STACKS

AUGUST, 1953

JOURNAL OF THE IRON AND STEEL INSTITUTE

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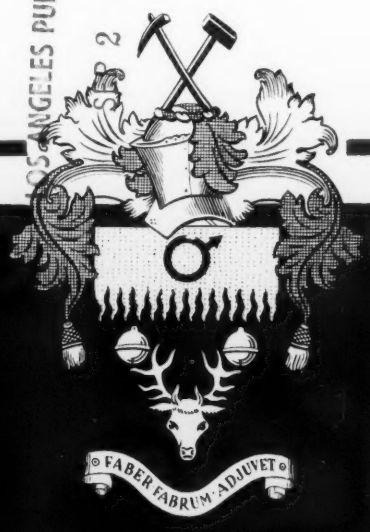

VOL. 174 PART 4

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Report of 21st Meeting of Engineers Group

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from START to FINISH

Ferodo Friction materials, both for putting the wheels of Industry in motion and bringing them to a standstill, play a big part in every day engineering practice.

They possess all the qualities essential to efficient economical operation: co-efficients of friction to meet widely varying operating conditions, exceptional anti-scoring properties and exceptionally long life.

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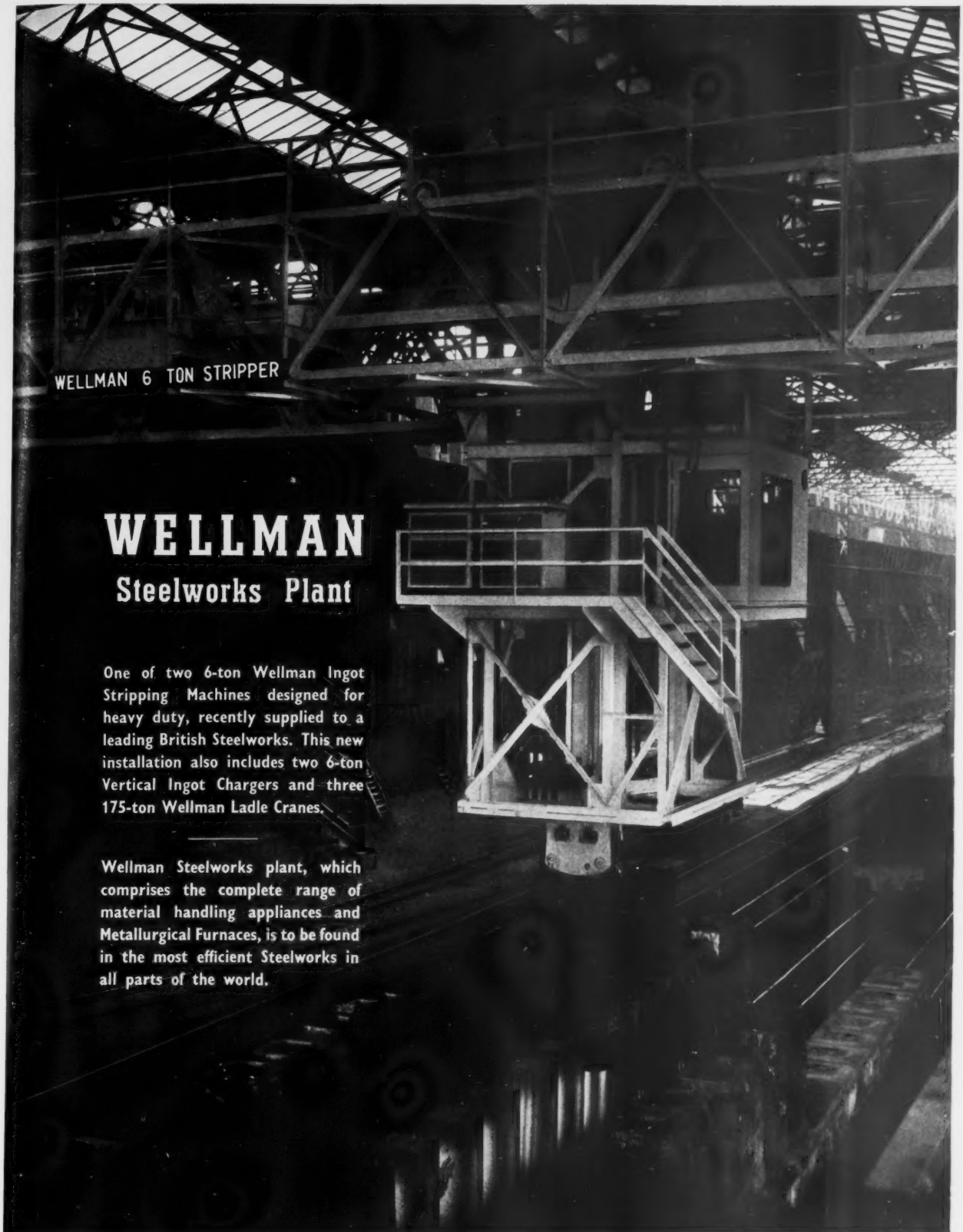

WELLMAN

Steelworks Plant

One of two 6-ton Wellman Ingot Stripping Machines designed for heavy duty, recently supplied to a leading British Steelworks. This new installation also includes two 6-ton Vertical Ingot Chargers and three 175-ton Wellman Ladle Cranes.

Wellman Steelworks plant, which comprises the complete range of material handling appliances and Metallurgical Furnaces, is to be found in the most efficient Steelworks in all parts of the world.

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KEEP THE POWER OFF UNTIL MAGNET SETTLES ON PILE

If you *don't*, smaller pieces will jump up to magnet and block off the rest so that you *can't* get a full load.

WORK ON DEEP PILES . . . YOU GET A BIGGER LOAD

The magnetism has a chance to take a full deep " bite " out of the pile.

KEEP BOLTS TIGHT

And replace broken bolts. Helps to keep moisture out, protects pole shoe against mechanical shock and helps to keep lifting power at maximum.

GREASE CHAIN LINKS AND KEEP THEM GREASED

Chain links constantly rub against each other causing friction and wear. Keep the links greased, keep friction down and your chains will last much longer.

DON'T USE MAGNET AS A BATTERING RAM

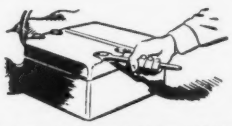
You may break a pole shoe, a terminal box, damage the windings, or rupture the insulation inside the magnet. *Use the magnet only for lifting.*

DON'T USE MAGNET AS SKULL-CRACKER

Many magnets don't wear out. They are broken—by careless handling. Don't drop a magnet to break up heavy pieces of scrap or to loosen a frozen ingot. *Use it only for lifting.*

SET YOUR MAGNET DOWN EASY

Repairs to broken magnets can be expensive and use up precious time. Ease your magnet down on to the pile.



KEEP TERMINAL BOX CLOSED

Keeps moisture away from terminals and protects them against breakage. If cover is lost, get a new one.

KEEP THE POWER OFF ON THE RETURN TRIP

The current heats the magnet and a hot magnet will not carry as much as a cool magnet. So discharge the load fast, keep the current " off " during the return trip, keep the magnet cool.

WHEN HANDLING HOT MATERIALS

Watch magnet temperature carefully and switch to spare magnet to avoid overheating.

INSTRUCTION SHEET 61113 SI, PRINTED ON HEAVY CARD FOR HANGING IN YOUR CRANE CABIN, CONTAINS 13 USEFUL OPERATION AND MAINTENANCE TIPS. COPIES CAN BE OBTAINED FREE ON APPLICATION TO PUBLICITY DEPARTMENT, BEDFORD.

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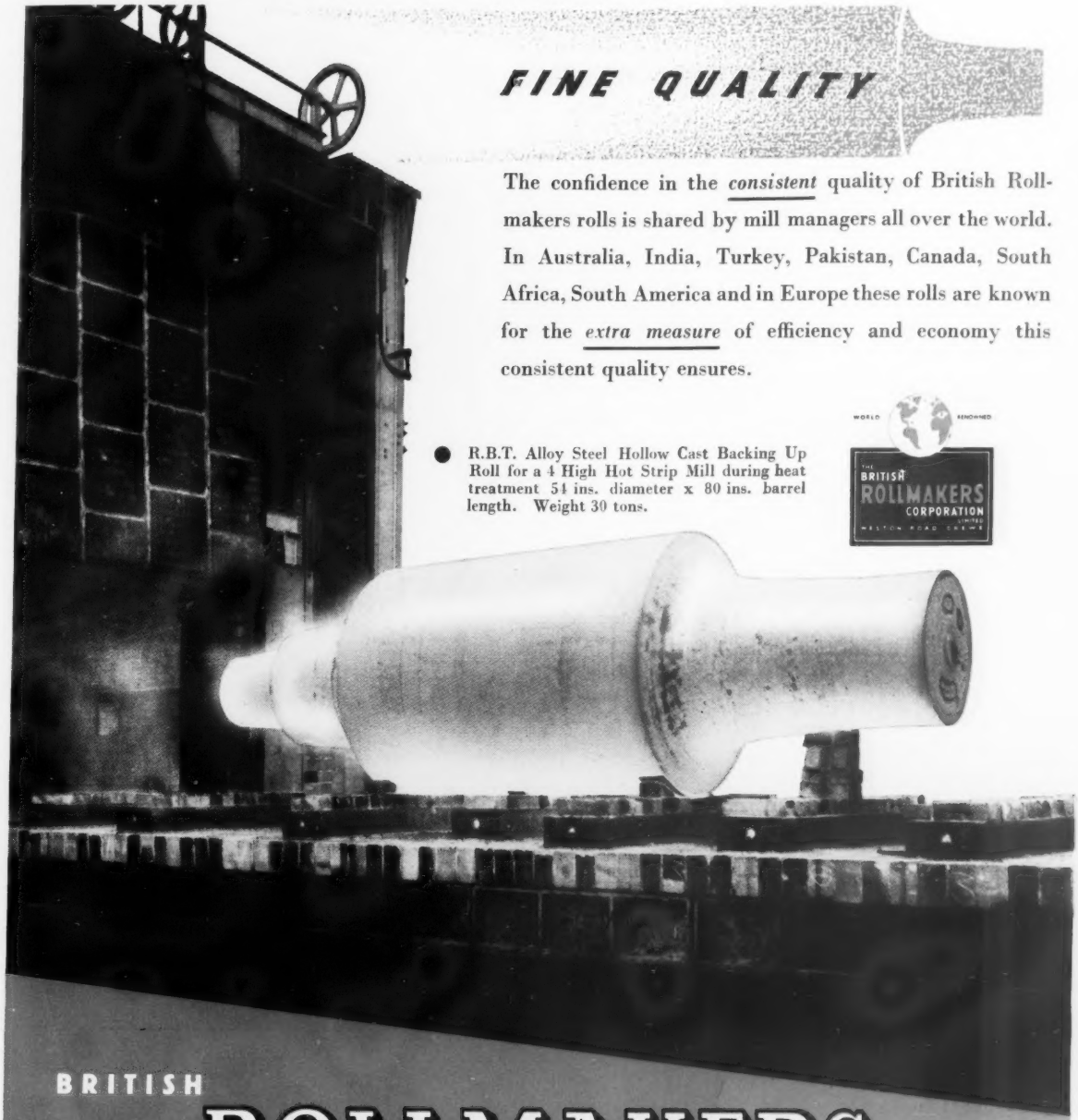

● R.B.T. Alloy Steel Hollow Cast Backing Up Roll for a 4 High Hot Strip Mill during heat treatment 54 ins. diameter x 80 ins. barrel length. Weight 30 tons.

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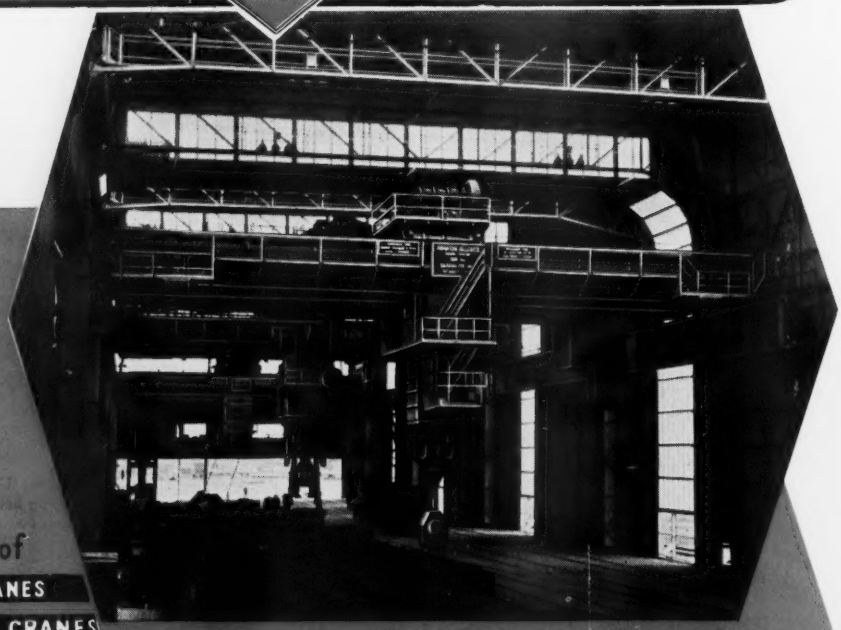

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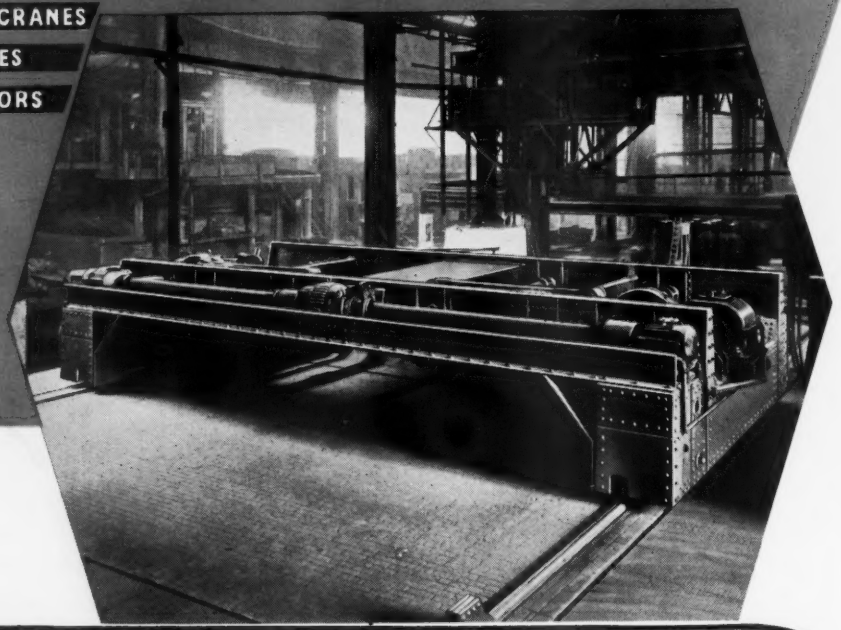

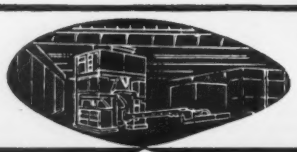

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"I shall get a rocket for this," sighed Guy Fawkes.

"What I wanted to do was to heat the place, not blow it up. But look at the fuel I had to work with! Now, if only I'd had oil fuel—and reliable advice on how to use it from Shell-Mex and B.P. Ltd.—I should have had everything under control. As it is, I suppose they'll be guying me for centuries as a supreme example of Uncontrolled Heat."

CONTROLLED HEAT WITH OIL FUEL

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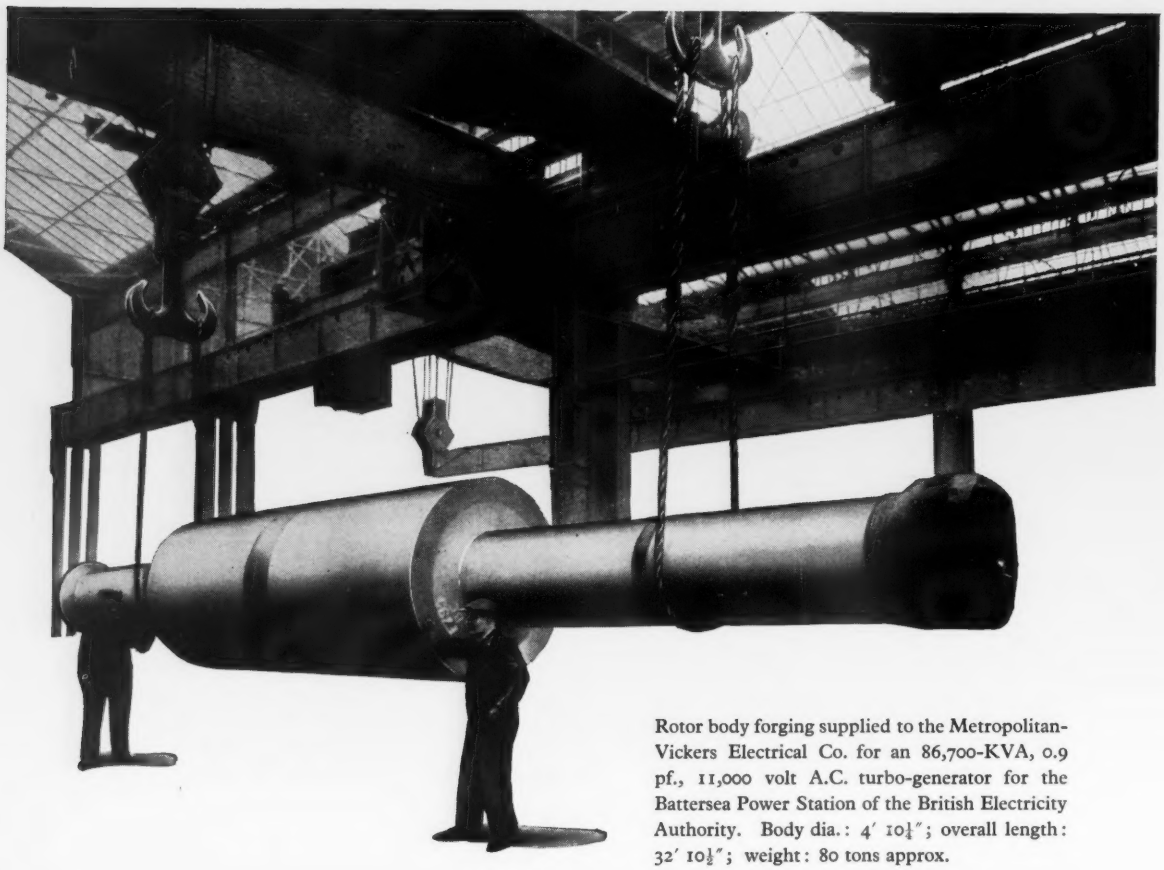

Rotor body forging supplied to the Metropolitan-Vickers Electrical Co. for an 86,700-KVA, 0.9 pf., 11,000 volt A.C. turbo-generator for the Battersea Power Station of the British Electricity Authority. Body dia.: 4′ 10¼″; overall length: 32′ 10½″; weight: 80 tons approx.

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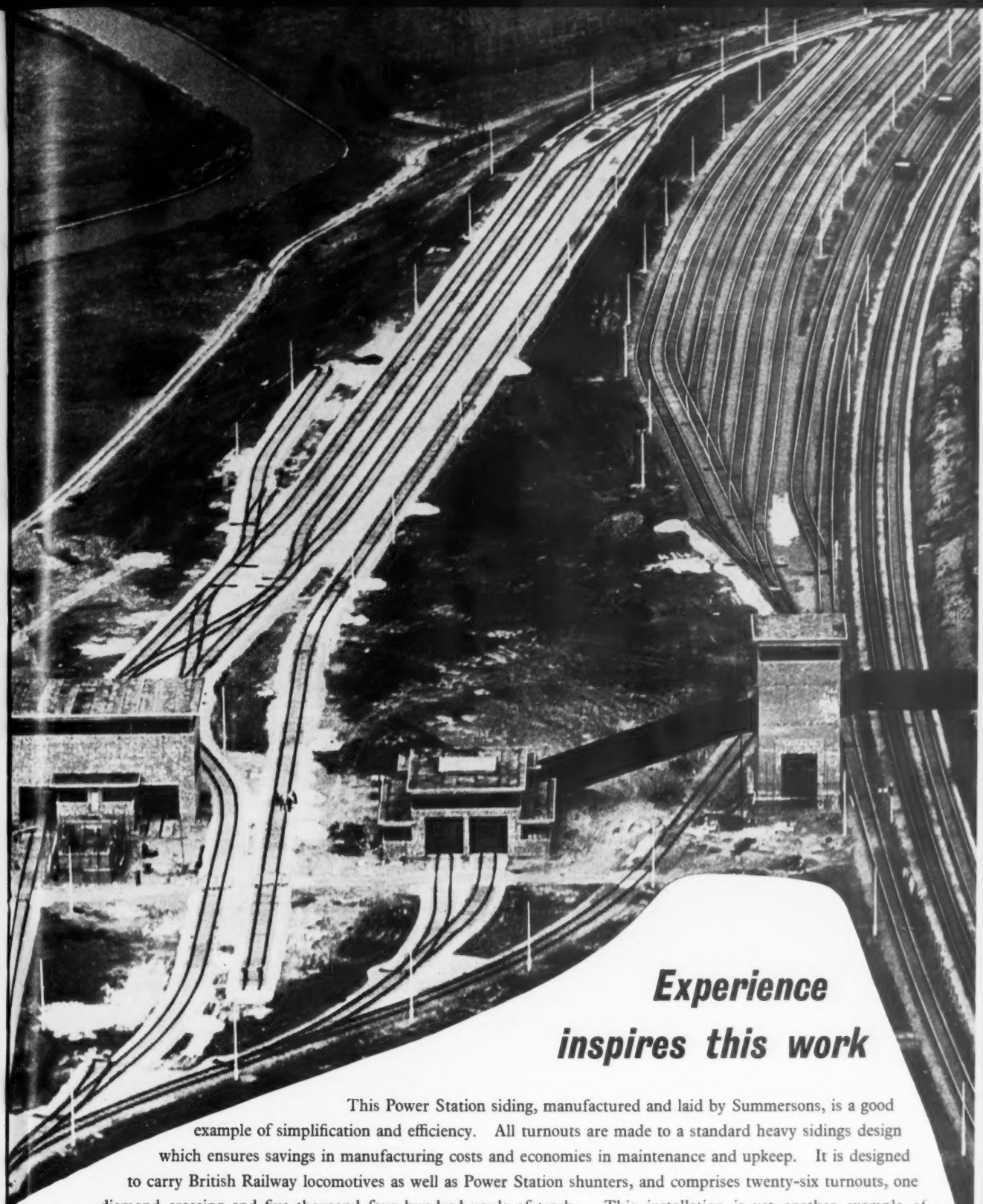

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We employ our own Erection Staff—hand-picked men with reputations for speed and efficient work who are available for quick and economic erection of structures in any part of the Country.

* 4 fold . . . FOUR SERVICES IN ONE . . . manufacture, design, fabrication and erection. At Cargo Fleet every phase of structural steelwork is effected within the resources of our own organisation. Four specialist departments contribute to the contract as a whole, but over all, there is top-level supervision which plans progress and ensures that work goes smoothly. In this way, handling costs are kept to a minimum, design is economical and steel gets to the site on time. If you consider "4 fold service" offers advantages, then contact Cargo Fleet for your next requirements in structural steel.

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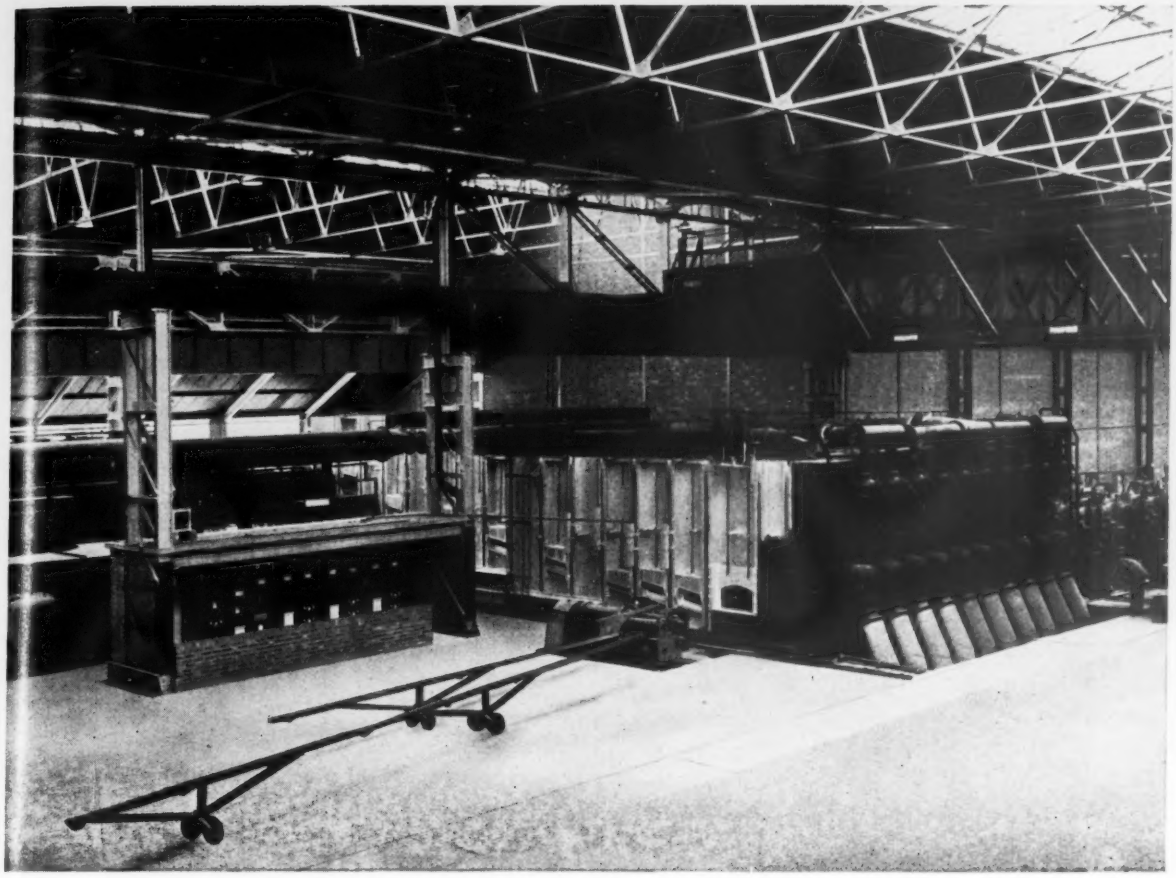

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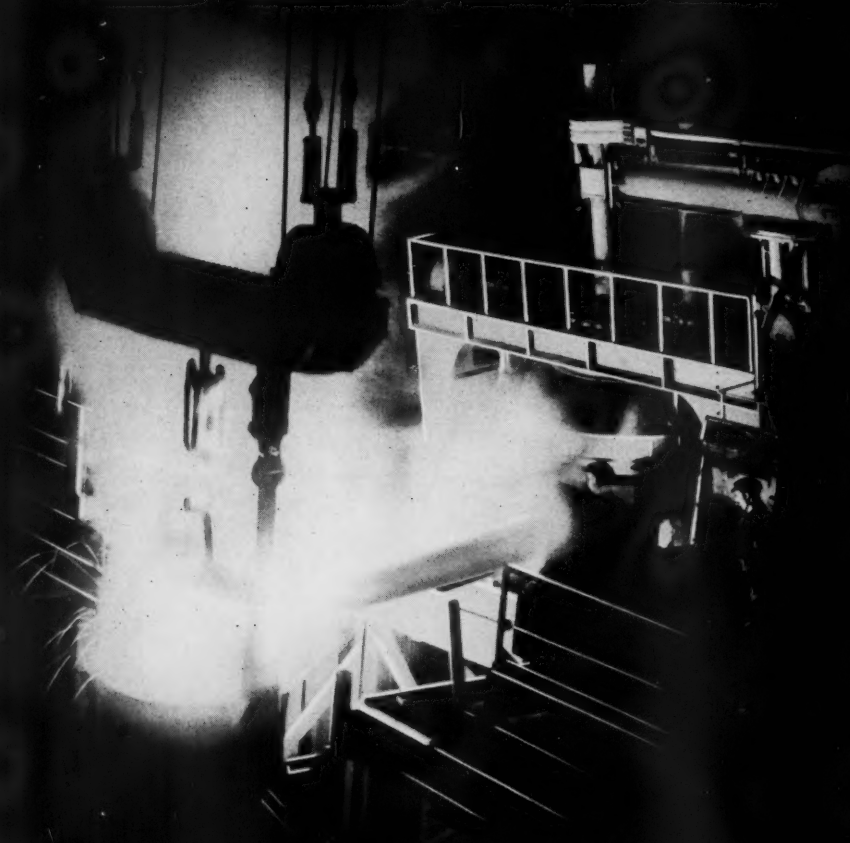

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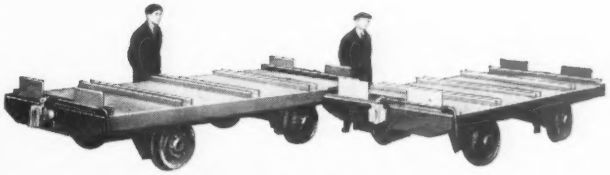

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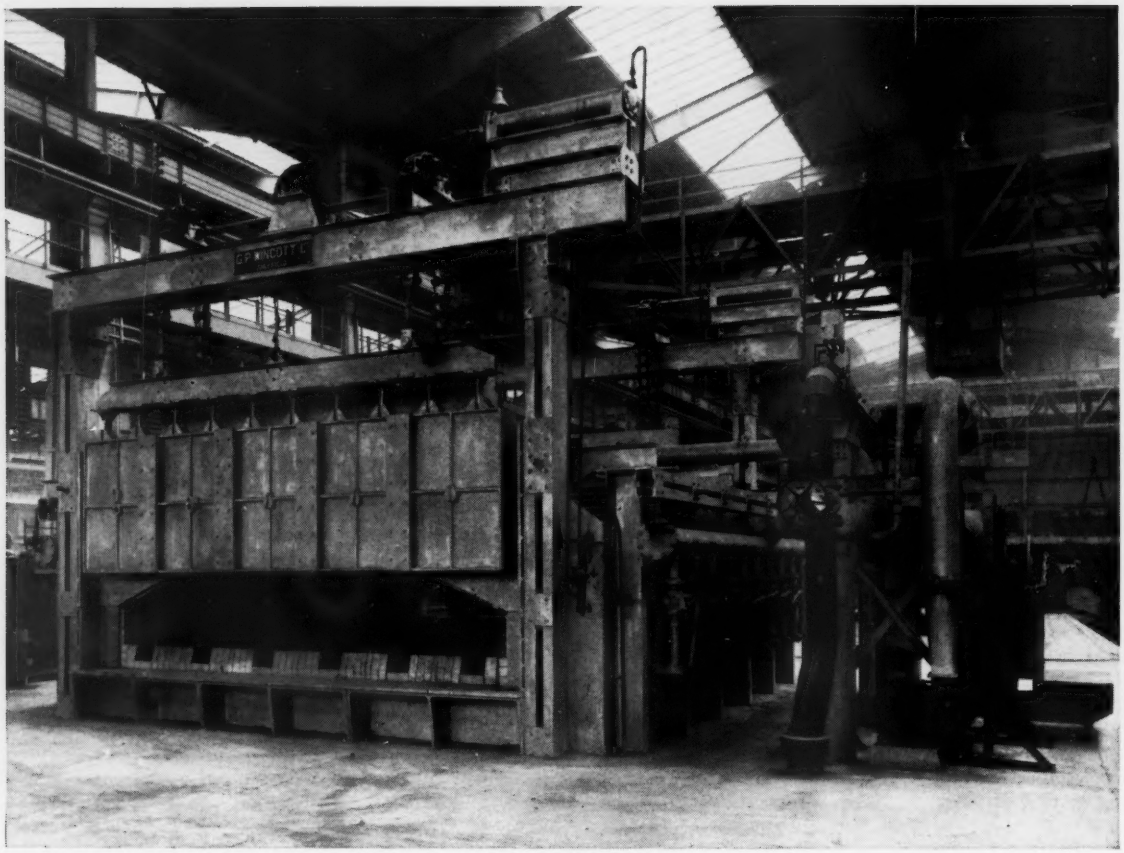

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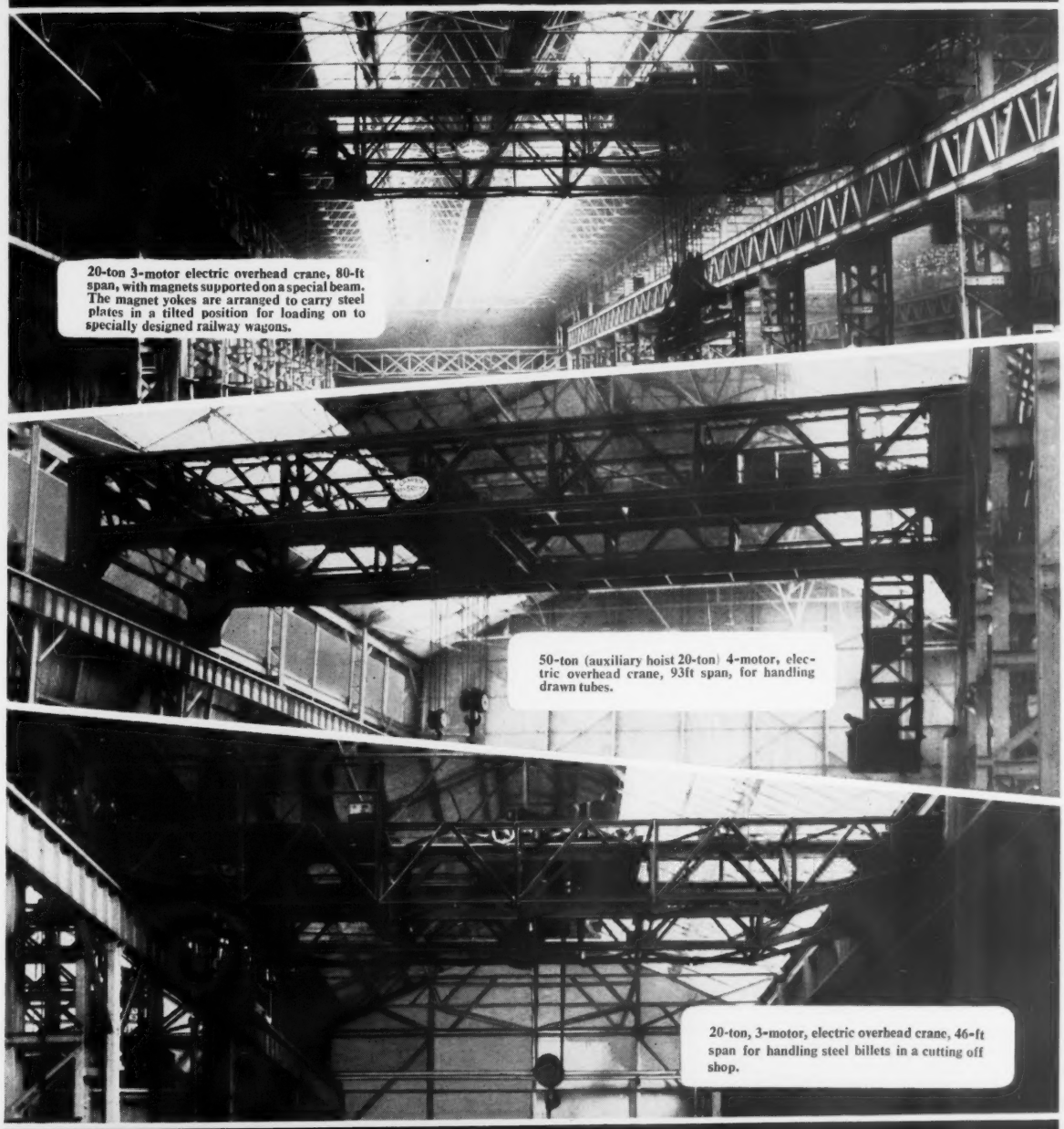

20-ton 3-motor electric overhead crane, 80-ft span, with magnets supported on a special beam. The magnet yokes are arranged to carry steel plates in a tilted position for loading on to specially designed railway wagons.

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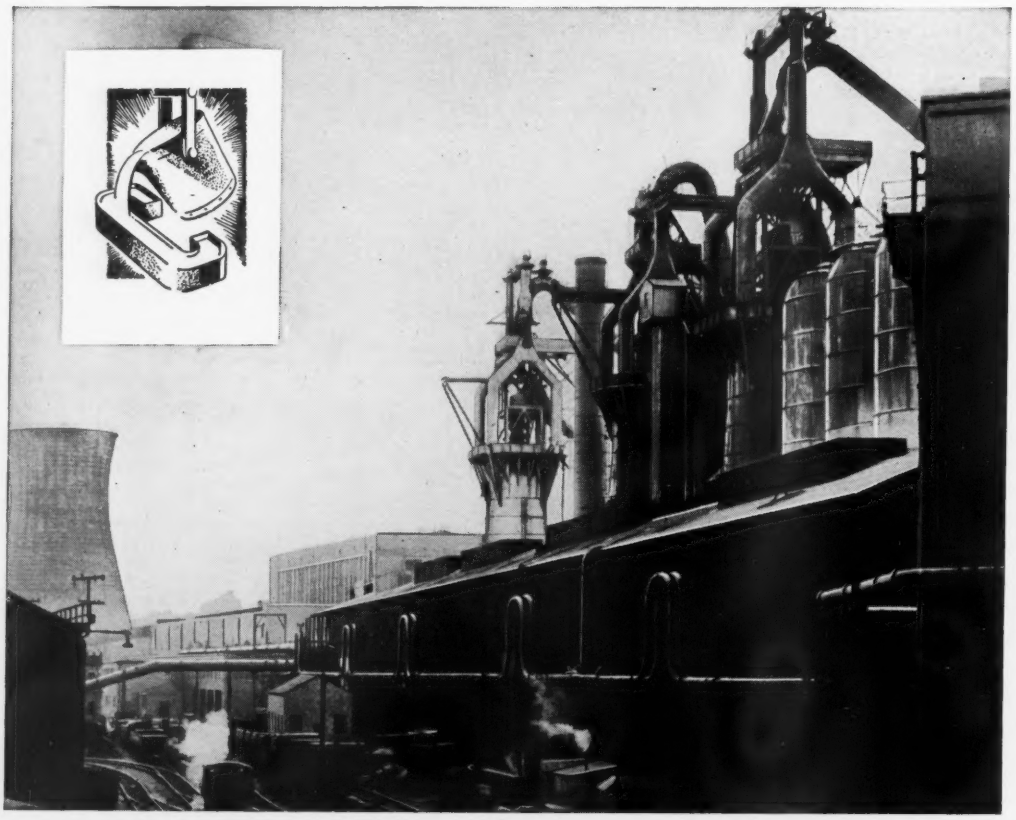

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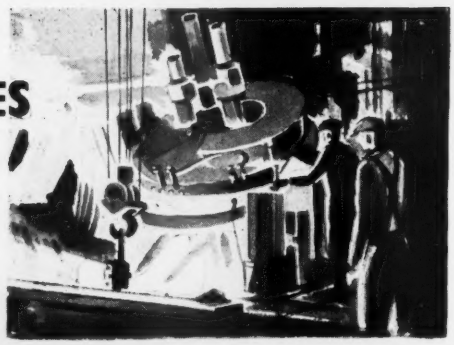

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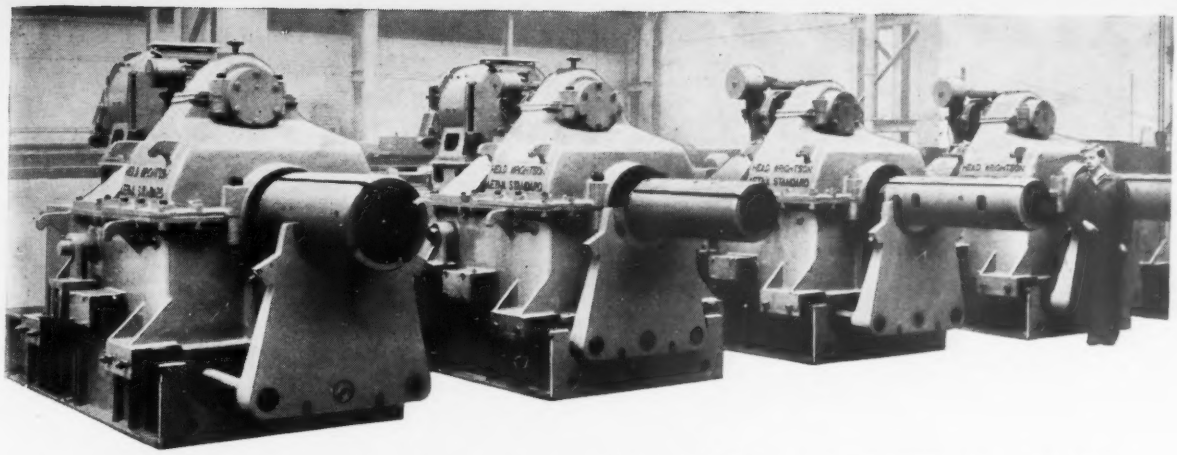


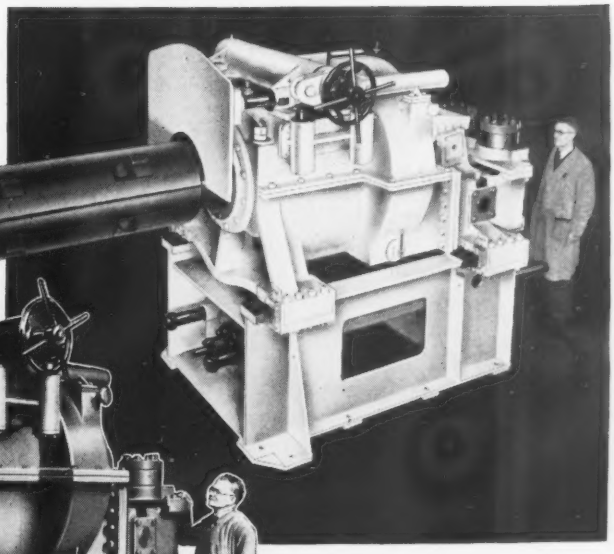
FOR COILING AND UNCOILING OF STEEL AND NON-FERROUS STRIP

CONSULT **HEAD WRIGHTSON**

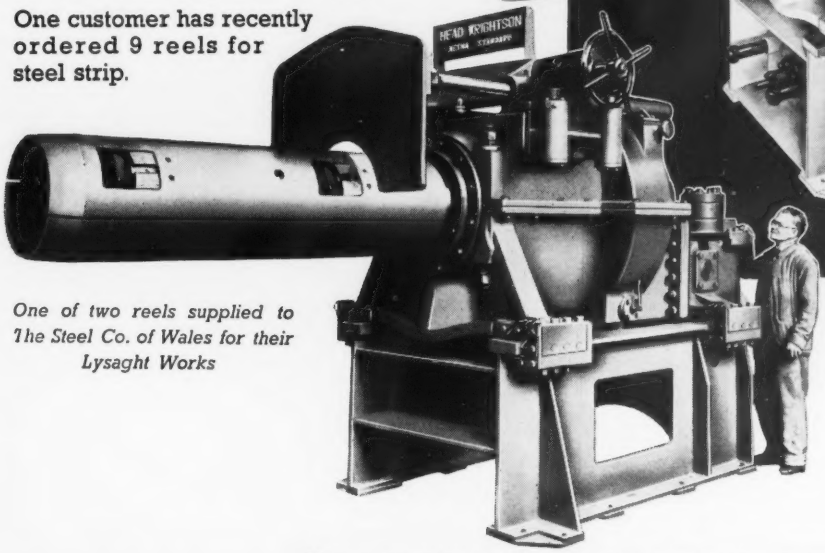
The four Head Wrightson pay-off and tension reels shown above represent part of an order for 7 which were supplied for temper mill, slitting line, and cut-up-lines handling aluminium strip.

Designs are available for many sizes and types of pay-off and tension reels. Units now being built are suitable for coils of 20 tons weight and 74" wide.

One customer has recently ordered 9 reels for steel strip.



One of three reels supplied to The Steel Co. of Wales for their Abbey Works



One of two reels supplied to The Steel Co. of Wales for their Lysaght Works

If you require cold strip mill equipment **consult**

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Illustration is of instrument panel at the Leatherhead factory of Messrs. Ronson Products Ltd., and shows a Brown ElectroniK Circular Chart Recorder and an Electronic Instruments meter for measuring and recording the pH value of a plating shop effluent.

pH

RECORDING & CONTROL

with

Electrodes and pH Meter by Electronic Instruments Limited
and Recorder/Controller by Honeywell-Brown Limited

WITH the increasing use of pH measurement in industry comes the need for instruments that permanently record the meter reading and, if required, control the pH value. By operating a Brown ElectroniK Circular Chart Recorder with an Electronic Instruments pH meter an accurate, reliable and permanent record of pH measurement is possible. Additionally, the Brown instrument is available with either electric or pneumatic control forms to maintain the pH value at a predetermined setting by automatically regulating the supply of the chemical re-agent. Both these instruments are manufactured by companies specialising in industrial instrumentation, and either Electronic Instruments Ltd. or Honeywell-Brown Ltd. have technical advice and assistance readily available.

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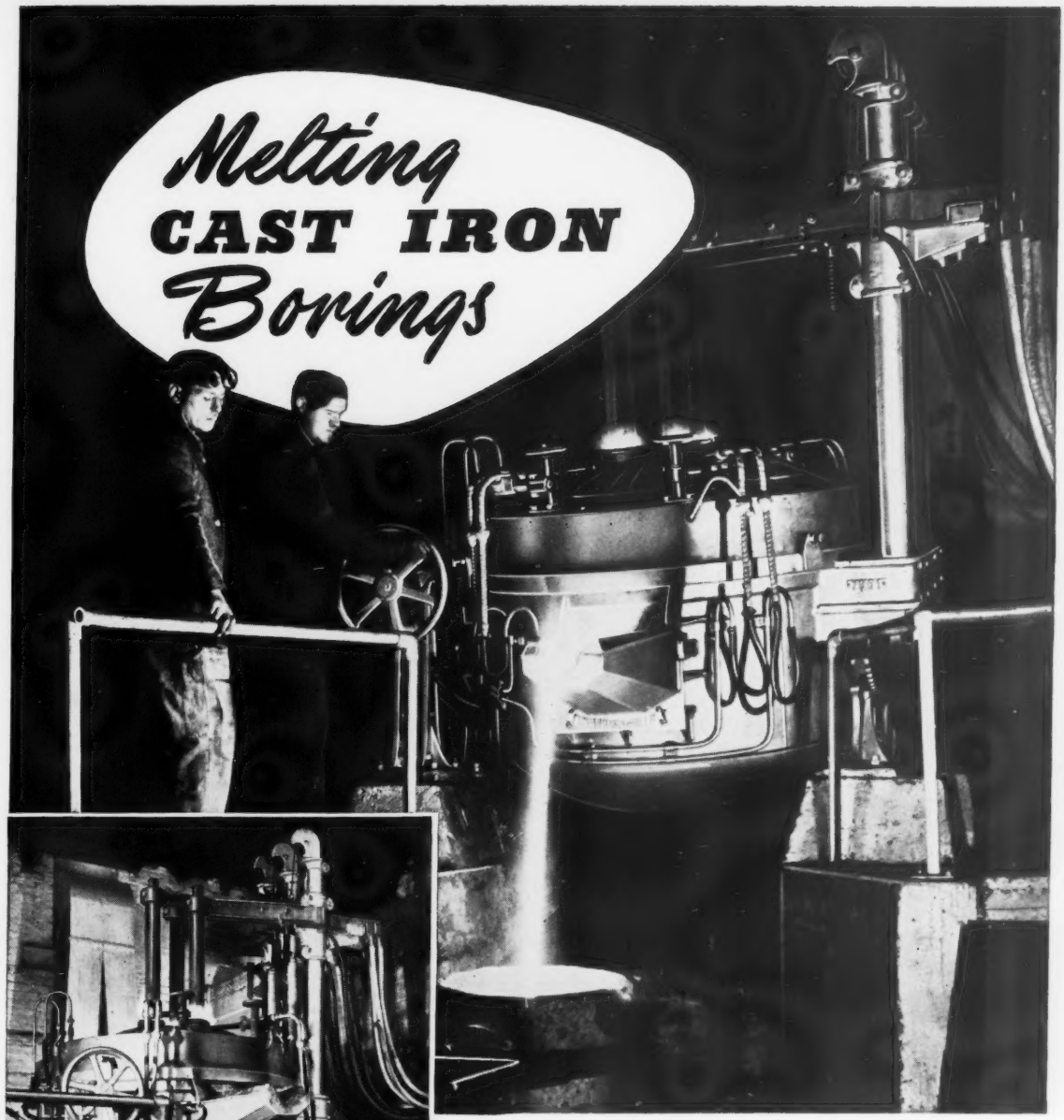

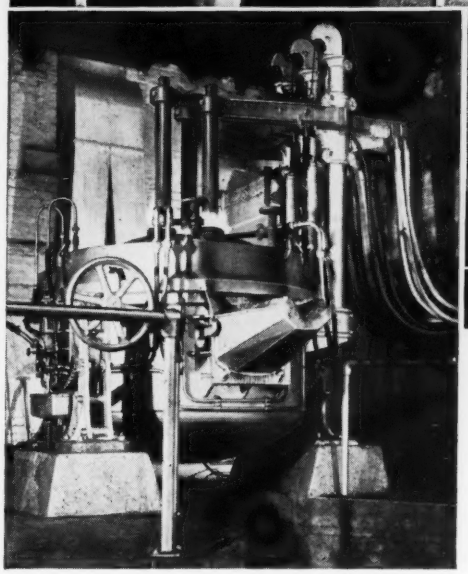

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Cliff's work is worth looking into!

WE LIKE TO THINK that this photograph of Cliff Jones reflects the infinite amount of skill and patience he possesses. As an inspector, Cliff enjoys an abundance of these attributes. His job is to examine work for flatness and straightness, as well as for surface imperfections. Visual inspection is only one of many types of examination meticulously carried out day and night by Cliff and other experienced inspectors. There's too much at stake to risk passing even the slightest flaw . . . .

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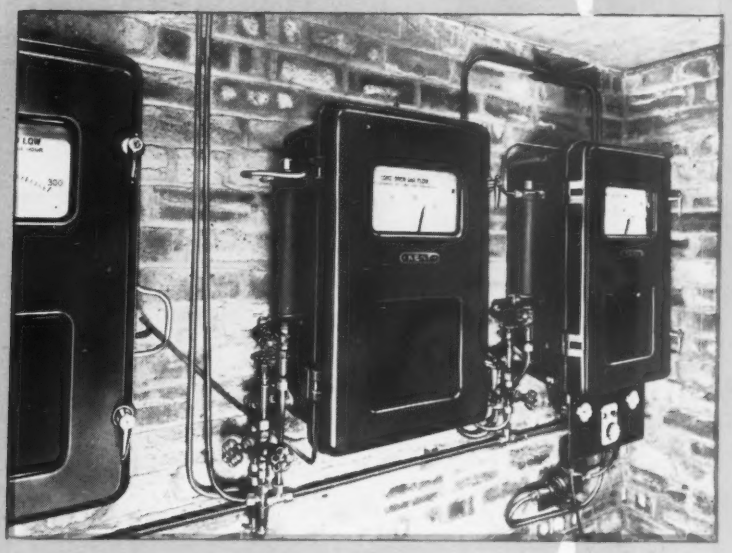
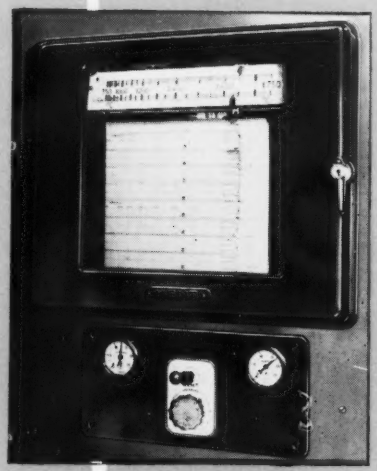


Summation of blast-furnace and coke-oven gas flows with combustion-air ratio control. Courtesy of Messrs. Colvilles Ltd.

FUEL CUT BY 4%



Roof-temperature controller actuating coke-oven gas flow. Courtesy of Messrs. Colvilles Ltd.

NO MID-CAMPAIGN REPAIRS

These are two of the significant advantages found by Messrs. Colvilles after they had installed automatic roof-temperature, combustion and furnace-pressure control equipment on "T" 350-ton tilting open-hearth furnace at their Clydebridge Works. For the first time in their experience, a tilting furnace completed campaigns without repair to roof or linings. The control equipment has operated continuously without failure and requires the minimum maintenance. They are able to maintain with safety, a higher constant roof temperature than with manual control; and combustion conditions are kept at the desired values. Furnace operators greatly favour the use of the controls. KENT supplied the roof-temperature and combustion control equipment, and have received repeat orders for two other furnaces at Clydebridge.

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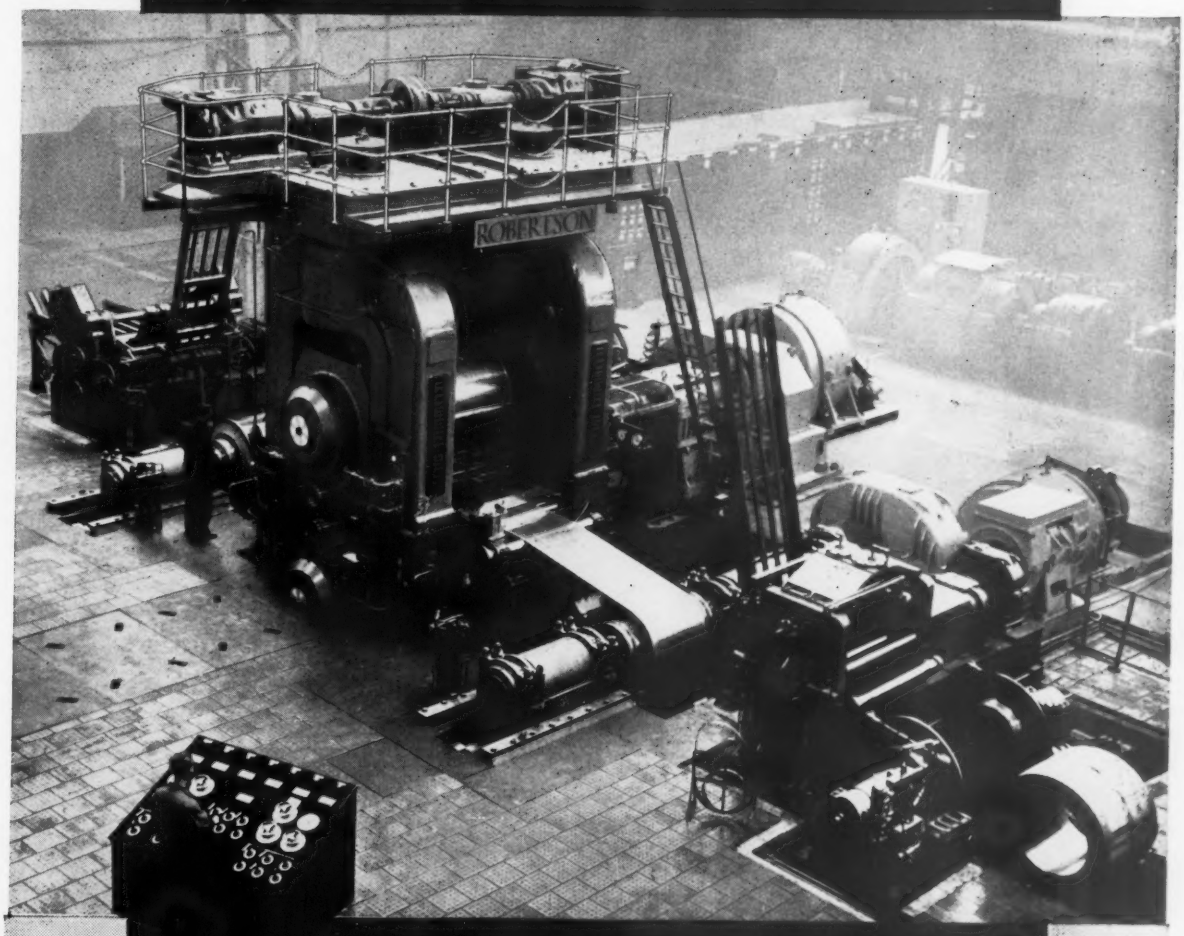

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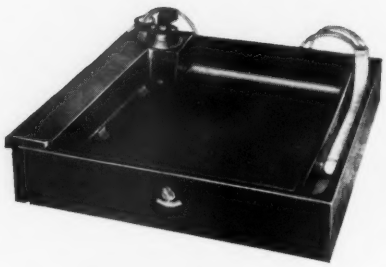

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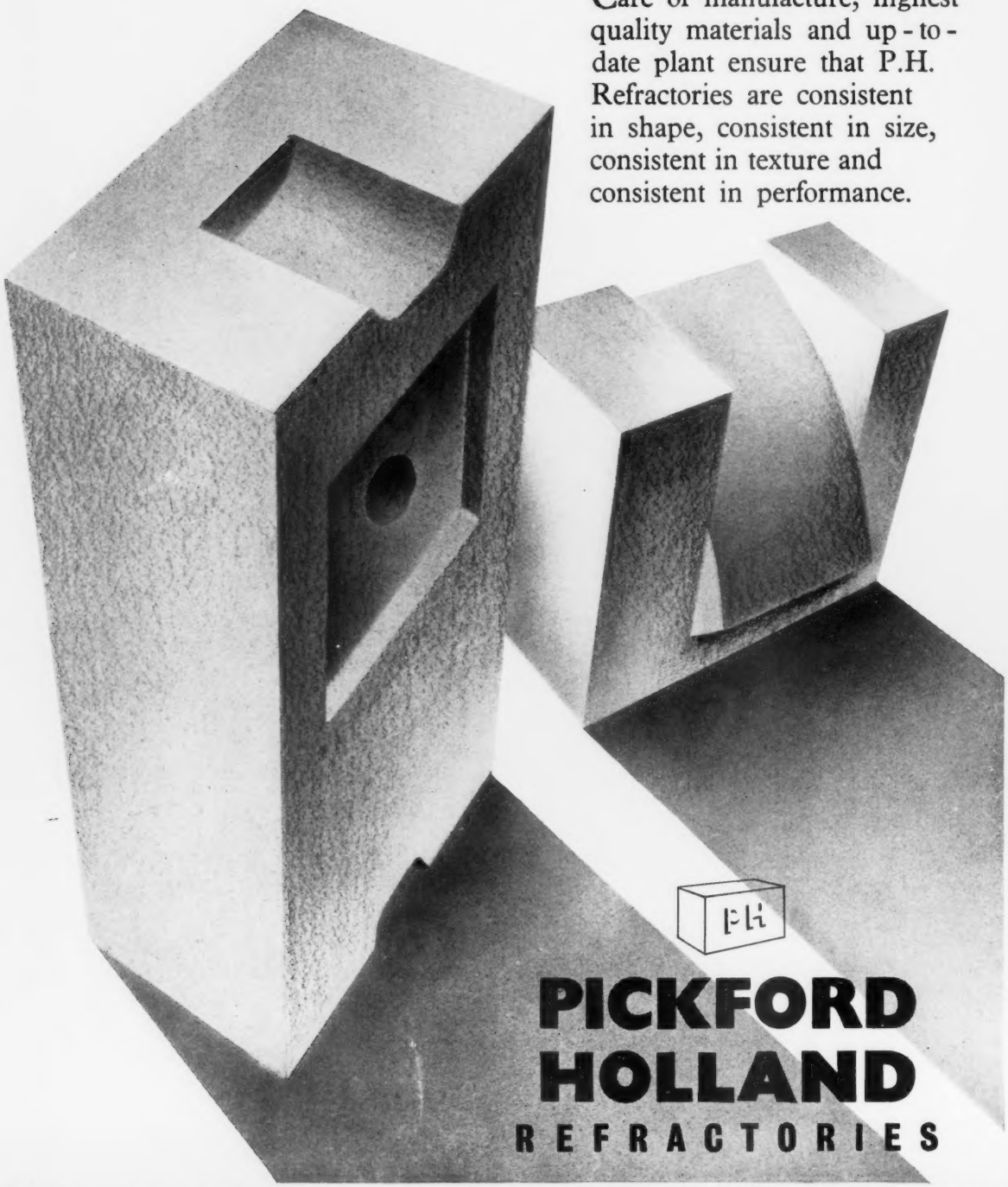

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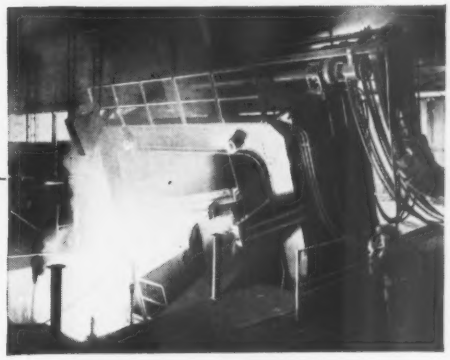
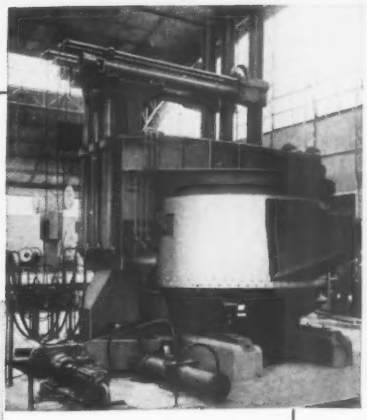


BRIDGE TYPE



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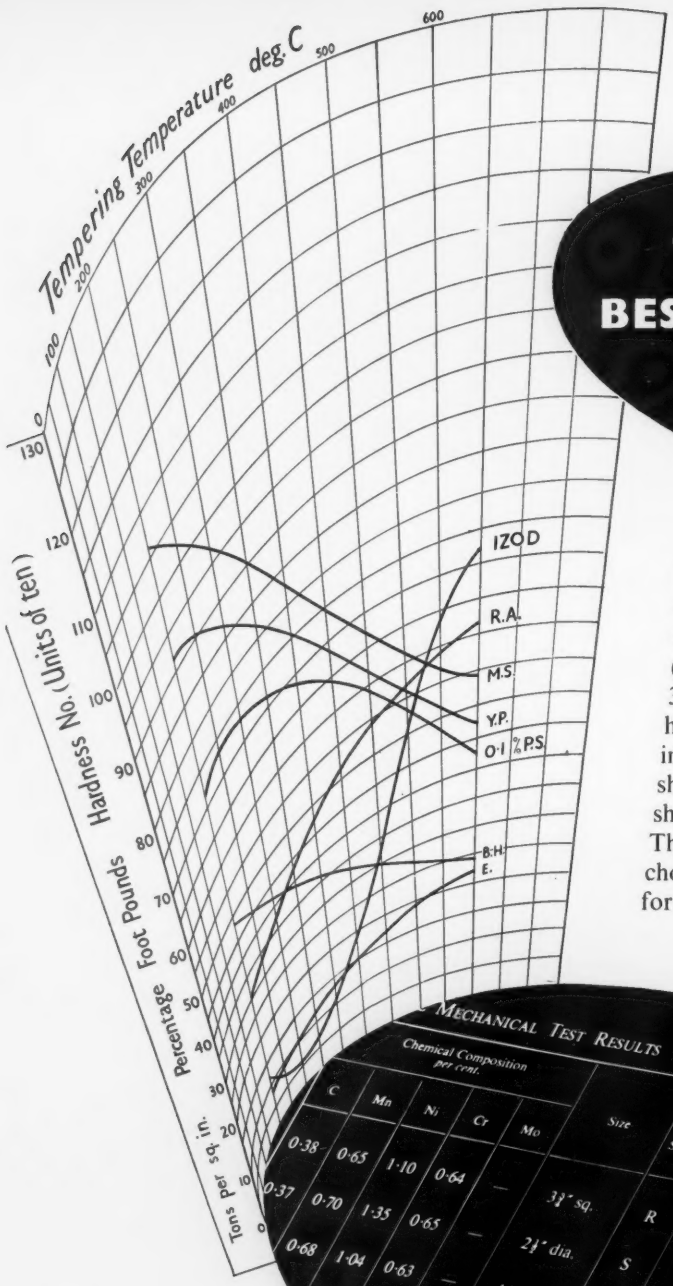

THE BEST STEEL FOR THE JOB

Our publication, "The Mechanical Properties of Nickel Alloy Steels" contains useful design data for a wide range of steels. Curves and tables of properties (such as these shown here) are given for 30 different direct-hardening and case-hardening nickel alloy steels, together with information on specifications and relationship between tensile strength, hardness, shear and torsional strengths.

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MECHANICAL TEST RESULTS

Chemical Composition per cent.					Size	Tensile Range Symbol	Heat-Treatment		Mecha		
C	Mn	Ni	Cr	Mo			Harden °C.	Temper °C.	Y.P. t.s.i.	M.S. t.s.i.	Elong per cent.
0·38	0·65	1·10	0·64	—	3½" sq.	R	O.Q.830	600	36·8	50·9	26
0·37	0·70	1·35	0·65	—	2½" dia.	S	,,	,,	47·4	55·6	22
0·68	1·04	0·63	—	—	1½" dia.	T	,,	,,	50·8	59·2	21·5
1·23	0·62	—	—	—	1½" dia.	U	,,	580	61·1	66·5	20·5

Tempering curves and table showing the properties obtainable with different ruling sections for a low nickel-chromium steel to Specification En 111.

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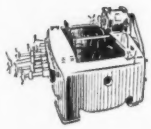
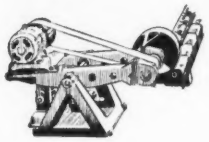
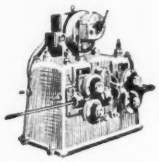
for the Tube Industry



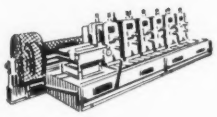
High Speed Tube Straighteners—for ferrous and non-ferrous tube ¼" up to 18" diameter with non-adjustable or adjustable angle driving rolls.



Tube Saws—High Speed Rocking type Saws and Flying Saws.

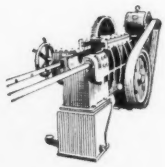


Close Joint Tube Forming Machines in three sizes from ½" to 5" diameter tube.

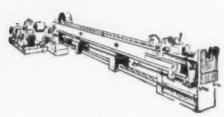


Tube Forming and Welding Equipment—for the production of close joint or welded tube from ½" to 6" diameter—with Sizing and Cutting-to-length Equipment.

Tube Testing Machines—for water testing of tubes ⅝" to 6" diameter—with hand or power operated Pumps and control gear.



Expanding and Reducing Machines in sizes to handle from ½" to 6" diameter tube.



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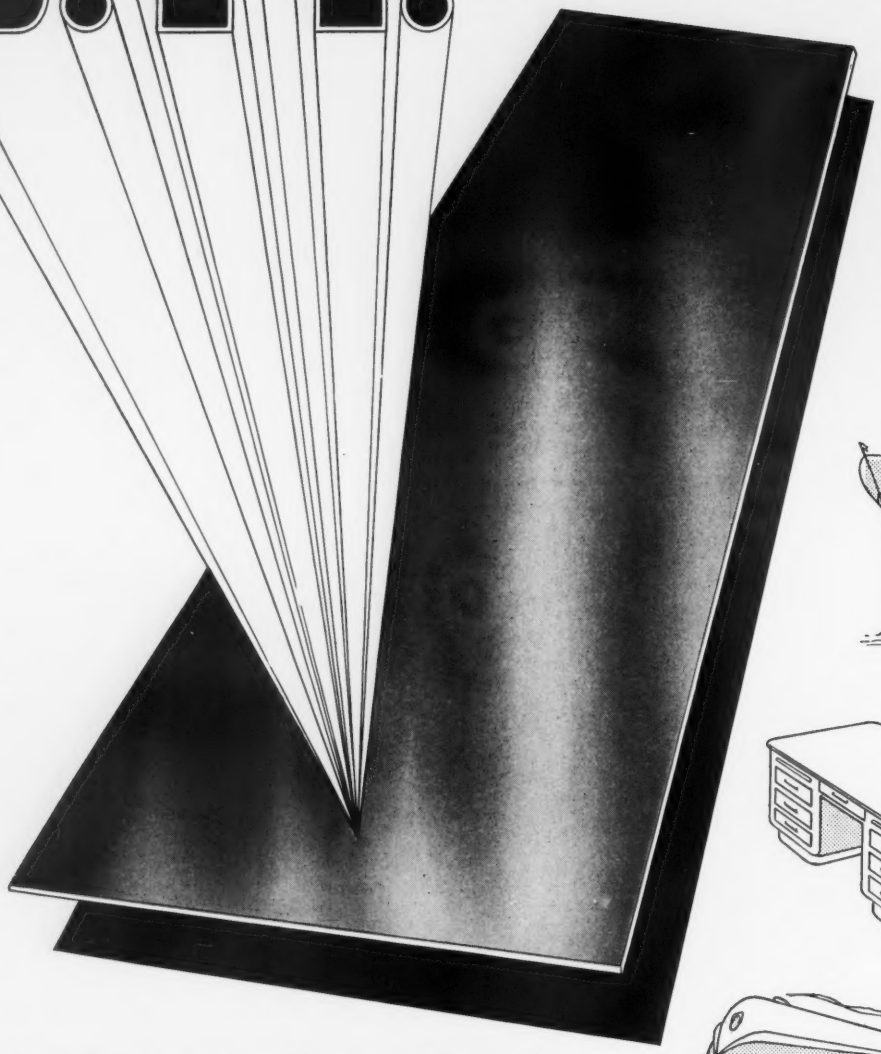

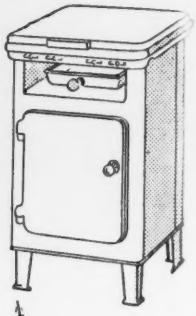

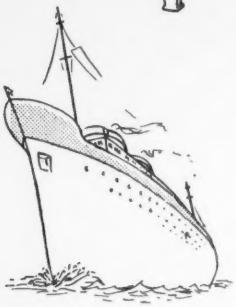

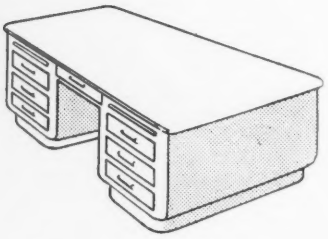

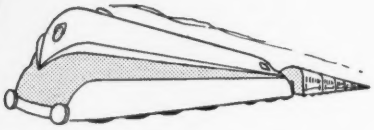

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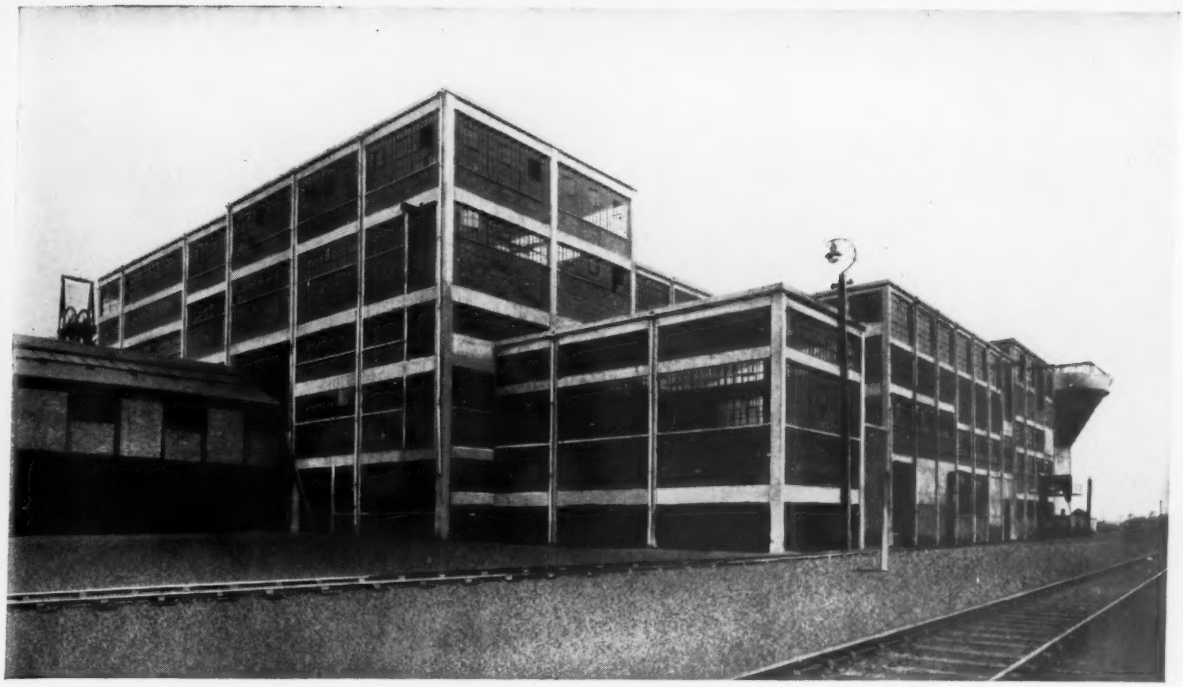

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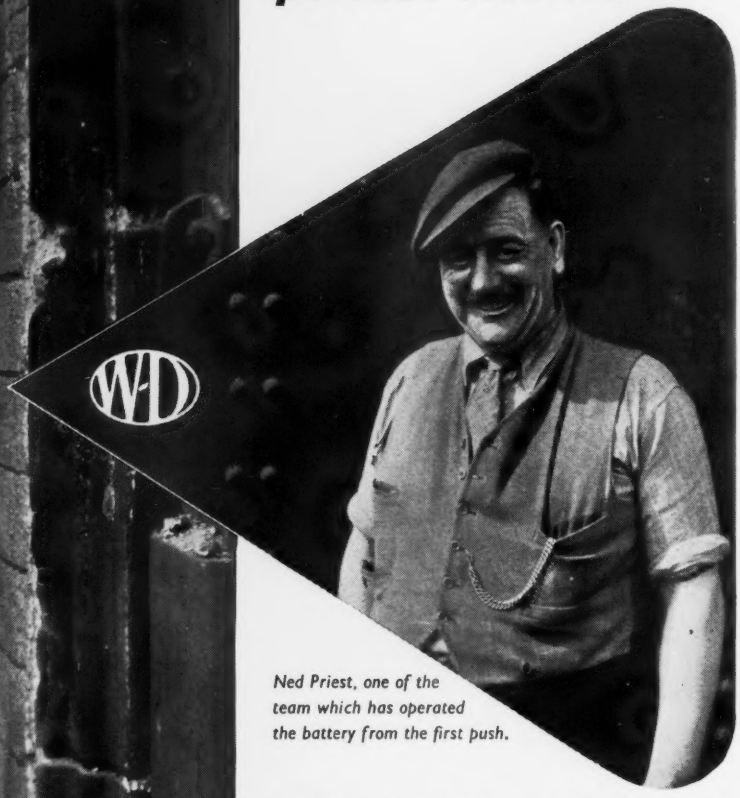

Ned Priest, one of the team which has operated the battery from the first push.

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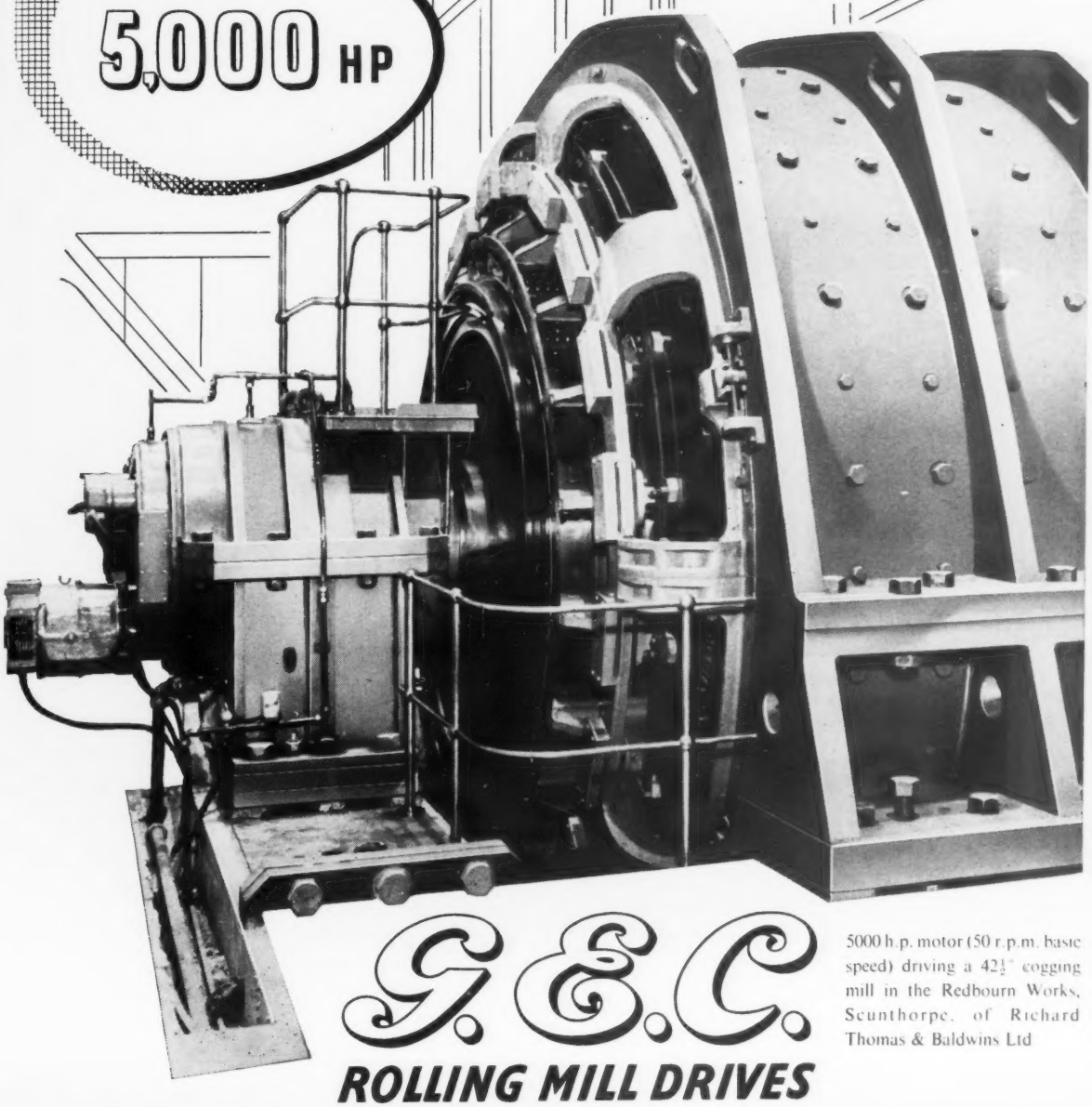

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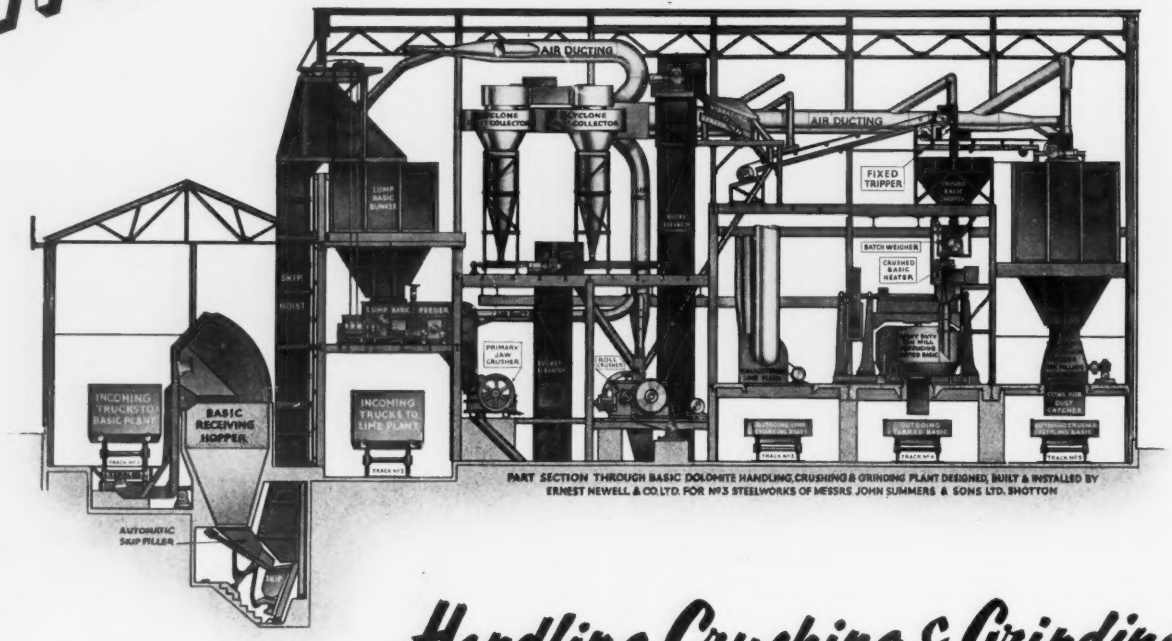

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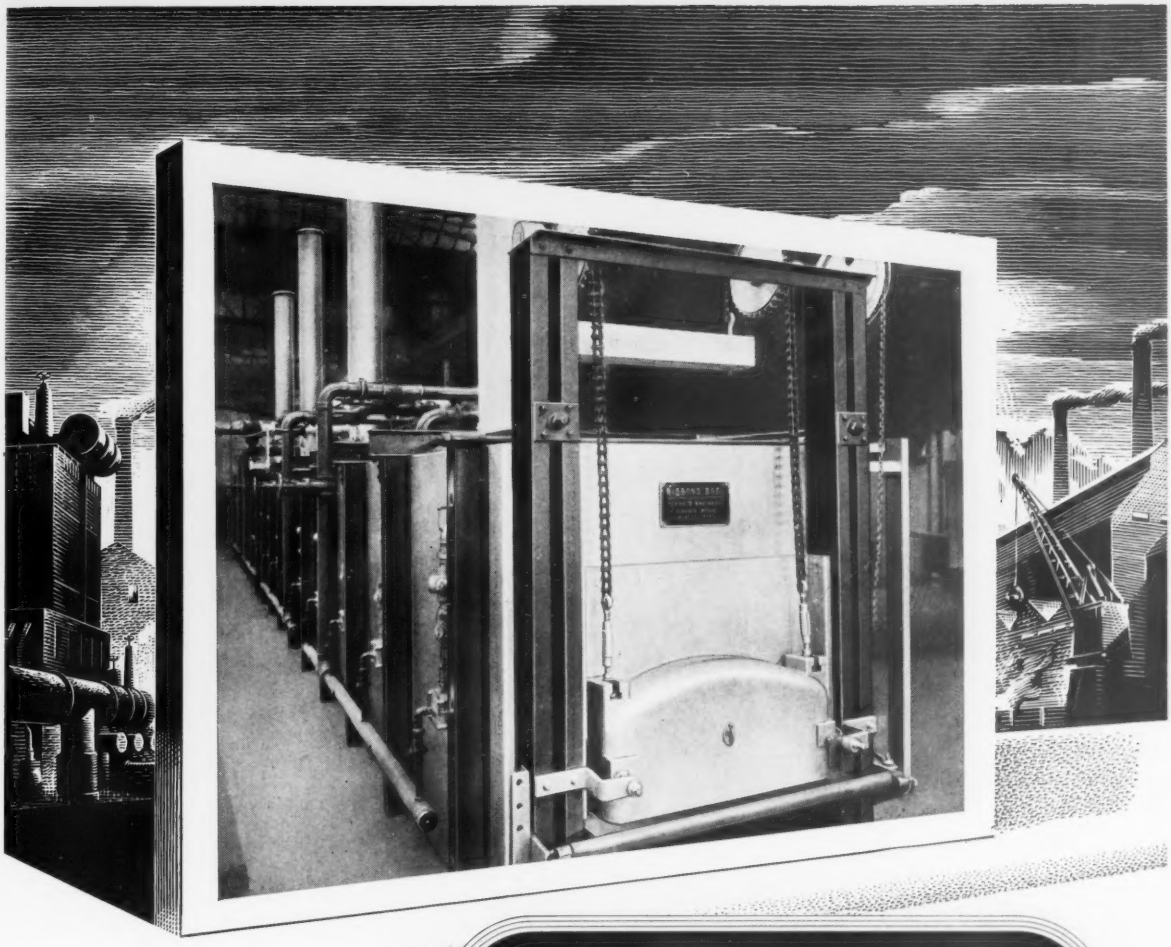

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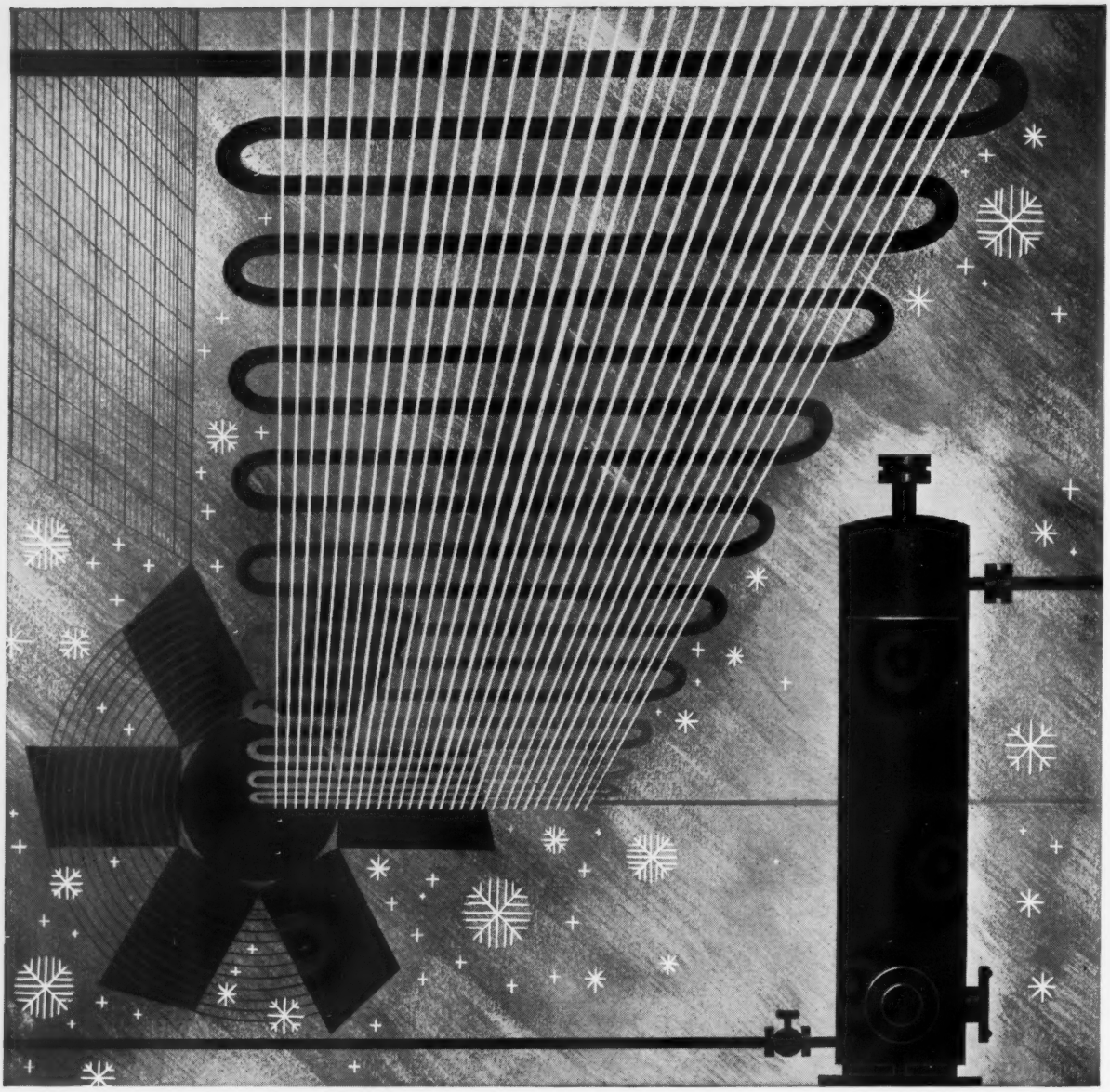

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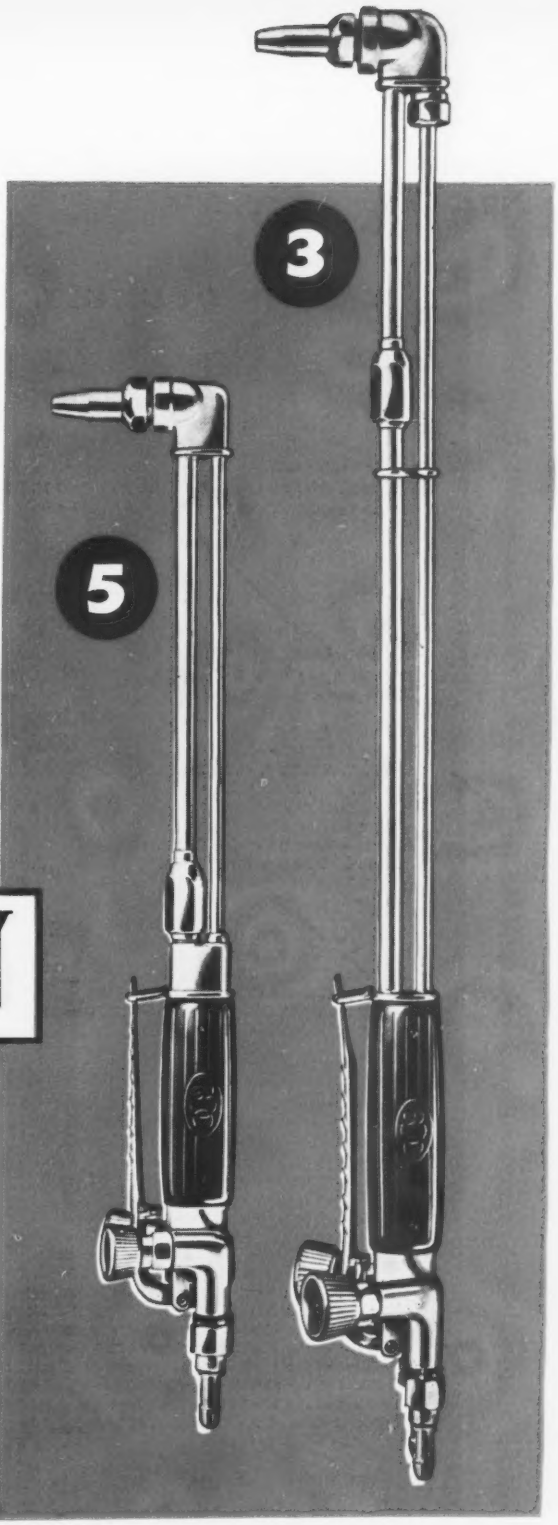

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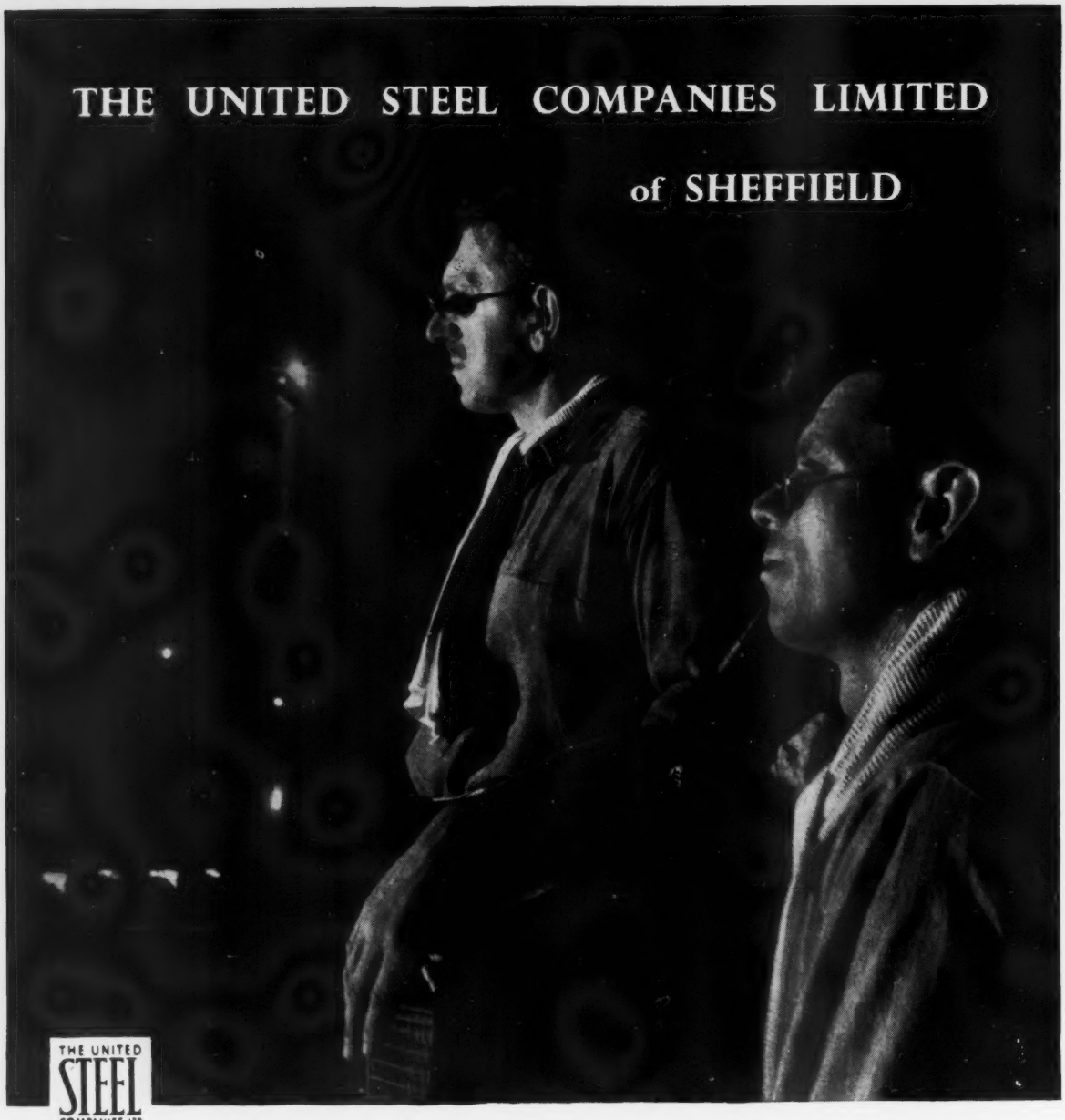

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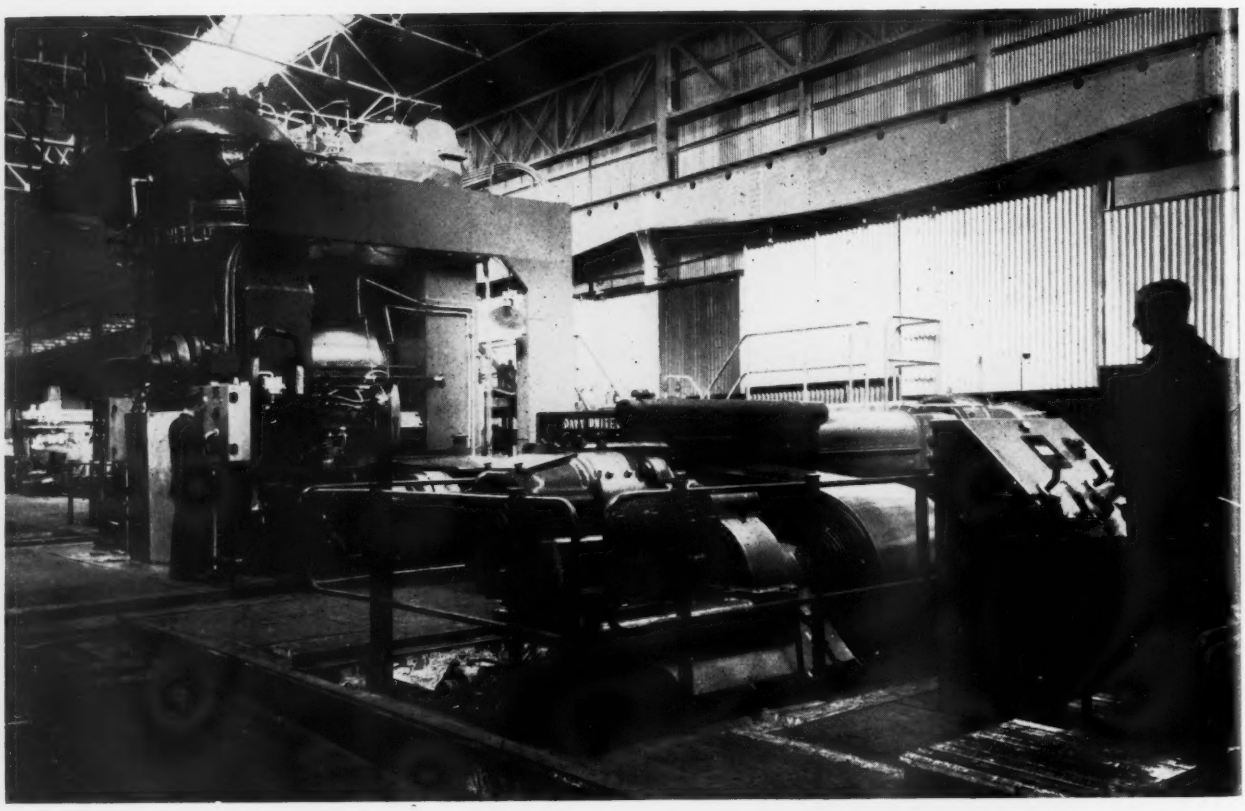

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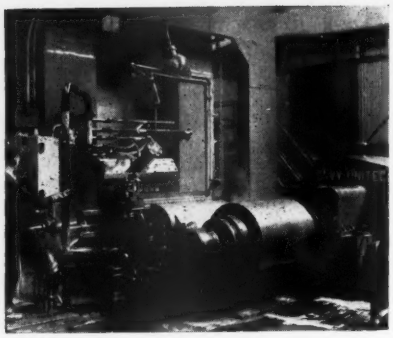

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LEONARD BESSEMER PFEIL was born in 1898, and was educated at St. Dunstan's College and at Woolwich Polytechnic, before spending three years at the Royal School of Mines, where he graduated in 1921. For the next nine years he held the appointment of Lecturer in Metallurgy at University College, Swansea, and during this period he published a number of papers on single crystals of iron and the mechanism of scaling.

In 1930 Dr. Pfeil joined the Research and Development Department of The Mond Nickel Company, Limited, as Assistant Manager in charge of the Research Laboratory at Birmingham, and during the following fifteen years he was responsible for directing research on a wide range of ferrous and non-ferrous materials. In addition to work in the Company's Laboratories on transformation characteristics of alloy steels, hardenability, the influence of alloying metals on response of steel to heat-treatment, constitution of non-ferrous alloys, high-temperature materials, and age-hardening of alloys, he has been closely associated for many years with co-operative investigations in the metallurgical field, in progress under the aegis of the British Iron and Steel Research Association, the British Cast Iron Research Association, the British Non-Ferrous Metals Research Association, and other organizations. He has also been called upon to serve on various Governmental Committees dealing with the properties and uses of metals and alloys, including the Inter-Service Metallurgical Research Council and the Metals Economy Advisory Committee to the Minister of Supply. He has taken an active part in the work of the Joint Education Committee set up by the five Metallurgical Institutes to consider the education of metallurgists.

During the war, Dr. Pfeil was responsible for researches on high-temperature alloys for gas turbines, which led to the development of the Nimonic series of alloys, and also for work on steels and other materials required for the war effort.

In 1945 he became Manager of the Development and Research Department of his Company, with headquarters in London, and in 1951 he was made a Director of the Company. He is also a Director of the associated firm of Messrs. Henry Wiggin and Company, Limited. He was awarded the O.B.E. in 1947, and in 1951 was elected a Fellow of The Royal Society.

Dr. Pfeil has been a member of the Institute of Metals since 1923; he has served on the Council of the Institute and has been Chairman of the Publications Committee. In 1946 he was elected a Fellow of the Institution of Metallurgists, and he is also a member of the American Society for Metals, the American Society for Testing Materials, the American Institute of Mining and Metallurgical Engineers, and the Electrochemical Society. He has been a member of The Iron and Steel Institute since 1926, and is now serving on the Council as the representative of the Institution of Metallurgists.

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AN AFFILIATED LOCAL SOCIETY PAPER

Some Factors Affecting Open-Hearth Steelplant Performance

By J. S. Curphey, F.I.M.

SYNOPSIS

Some of the more practical factors affecting steelplant performance are outlined, with particular reference to the hot-metal practice at the Redcar Works of Dorman, Long and Co., Ltd. The importance of shop and stock-bay layout is stressed. In discussing the raw materials the paper refers to oil-fired mixer practice and the effect of increasing the proportion of hot metal in the furnace charges. Slag bulk and flushing practice are dealt with, and there is some comment on foaming slags. Factors affecting the efficiency of fuel combustion are discussed, and it is shown that the nature and degree of refractory wear are influenced by furnace design. Steps taken to improve ingot quality and mould consumption are described, and the paper concludes with a reference to some of the human factors involved. 771

THE primary function of an open-hearth steelplant is to produce, at the minimum cost and over a long period, the maximum tonnage of steel suitable to the purpose for which it is intended.

An attempt will be made to outline some of the more practical factors that affect the performance of this function and, whilst the subject will be treated from a general standpoint, reference will be made to the Redcar steelplant, which consists of ten 90-ton fixed basic furnaces and one 350-ton active mixer. All units, including the mixer, are oil-fired. About 80% of the product is used for rolling into plates at Redcar, the remainder being dispatched to other works within the Company to be rolled into billets, sections, or sheet bars.

Although some of the factors may be generally applicable, others apply only to groups of plants having similar practices. Furthermore, the performance of an individual plant may be considerably influenced by local conditions (raw materials and environment) peculiar to it, and this should be borne in mind when comparing the productivity of plants.

From the design of the plant to the teeming of the ingot, steelmaking is a process governed largely by compromises, and, although fundamental principles may often be applied, many decisions can be made only after careful balancing of advantages against disadvantages and by the application of common sense.

OPEN-HEARTH PRACTICE

Shop Layout

One of the first essentials for smooth working is that the shop layout should be such as to ensure that the raw materials are delivered and fed to the furnaces and the products are disposed of with the minimum of delay. On many plants lack of space and other factors have made it impracticable to develop supply and handling systems to keep pace with the higher output potential resulting from improvements in furnace design, increasing furnace capacity, and more efficient metallurgical and fuel practices. The foresight shown in the original design of the Redcar plant has, however, facilitated the development of supply and charging systems and of equipment for disposal of the product to maintain a reasonable balance with the higher furnace productivity.

Stock-Bay Layout

With the bench-loading system of charging, delays will be minimized when the stock-bay layout fulfils the following requirements:

(i) There are at least two independent entry roads

(ii) The stock-bay floor is high enough for the wagon tops to be in the same horizontal plane as the tops of the charging boxes on the bench. Apart from facilitating rapid loading, this arrangement minimizes wagon and rail damage. At Redcar the stock-bay floor is at valve-arch level, necessitating a hoist travel of 18 ft.

(iii) The crossings are arranged to permit the setting of scrap wagons, with the minimum of shunting, opposite the furnace being charged. Table I, which is a summary of time studies on magnet-crane operation, illustrates this point. Adequate wagon standage, although in itself an advantage, is of no use if shunting difficulties lead to empty wagons standing for long periods

(iv) Subject to the above requirements, crossings should be kept to a minimum and sited to reduce the probability of damage by scrap falling from the magnets

This paper was presented to the Cleveland Institution of Engineers at a meeting held on 16th February, 1953, at the Cleveland Scientific and Technical Institution, Middlesbrough.

Mr. Curphey is Steelplant Manager at the Lackenby Works of Dorman, Long and Co., Ltd., and was formerly Steelplant Manager at the Redcar Works of the same Company.

(v) If possible, sufficient floor space should be provided to stand boxes, which can be loaded when magnet cranes are otherwise idle owing to lack of bench space. Figure 1 shows the stock-bay layout at Redcar.

Charging

The optimum charging rate of a furnace will depend on the type of scrap used and the rate of heat transfer to the charge (this may differ between furnaces and even on an individual furnace during its life). The rate at which an oil-fired furnace will accept scrap will be much higher than with, say, producer-gas

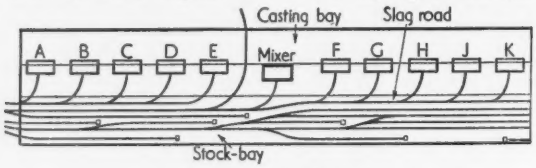


Fig. 1—Plan of stock-bay

firing, and, to take full advantage of the higher heat-transfer rate, the charging must be speeded up. The stock-bay organization must make the fullest use of crane power, and as much as possible of the cold charge should be loaded into boxes before the furnace taps the previous heat. With the pan-bench system of charging, bench room is at a premium, so that additional standage space for loaded boxes is useful.

The bulk density of the scrap has a major effect on the charging rate, and the wide range of charging-box capacity with various types of scrap can be seen from the following figures:

Type of Scrap	Box Capacity, cwt.	No. of Boxes per 40-ton Charge
Light bundles	4·4	182
Medium bundles	6·6	121
Light bought scrap	3·9	205
Medium bought scrap	8·6	93
Plate mill	12·7	63
Mill crops	25·6	32

Mean charging rate: 62·8 boxes/hr.

The sequence of charging is as critical as the charging rate; at Redcar about 6 tons of scrap are charged on the bottom, followed by the limestone and ore and the remainder of the scrap. Unless charging delays are experienced, a high fuel input is required at this stage, the steam/oil ratio being adjusted to produce a short keen flame, and it should only be necessary to interrupt charging when appreciable amounts of very heavy scrap have been charged or when bulky scrap, such as light bales, fills the available space in the furnace. The aim is to marry the fuel input and the charging rate so as to attain rapid melting, while avoiding steep temperature gradients through the charged materials.

Erratic charging and low fuel rates can only result in unsatisfactory conditions of the metal and slag at melt. If the scrap on the bottom is allowed to liquefy before the remainder is added, or if heat input has been too low during the charging of heavy scrap, difficulties will be experienced in melting, and a sluggish bath and unmanageable slag will result in a prolonged refining time.

Raw Materials

It has long been recognized that the quality of the molten iron has a considerable influence on the production rate of an open-hearth furnace, and during the past 20 years numerous papers have been published that show the quantitative effect of the chemical composition of the iron on slag bulk, mineral consumption, and refining time. It would, therefore, be superfluous to dwell on a subject that has been so fully discussed and on which there can be little controversy. The Redcar steelplant has benefited to a large extent from the regular and high quality of the iron produced at the Redcar blast-furnace plant.

Although the physical condition of the iron is not so easily measurable, it is nevertheless an important factor. Iron temperature and the degree of freedom from slag are interrelated factors and the difficulty of separating slag from shoddy iron is well known. In the case of mixer iron, it is usually possible to supply the furnaces with iron comparatively free from slag, but care is needed when the metal level is low, as, for example, when emptying for fettling. Heavy fettling on steel furnaces, sometimes experienced after periods of direct iron charging, might be due not only to the higher percentage of metalloids in the iron but also to blast-furnace (or mixer) slag introduced with the metal.

Owing to the impracticability of obtaining representative samples of bought scrap, it is difficult to correlate quantitatively the scrap quality and productivity. This factor nevertheless has considerable influence on furnace performance. Bulk density, shape, and size all have their effect on handling and charging rates, and entrained non-metallic materials such as clay, sand, and concrete, in addition to their influence on the nature and bulk of the slag, can have detrimental and sometimes catastrophic effects on the furnace hearth. Copper and tin tend to promote intergranular weaknesses in the rolled product. Other undesirable non-ferrous metals are aluminium, the oxide of which tends to promote foaming of the slag, and lead, which, owing to its low melting point and high specific gravity, finds its way through the sub-hearth.

Experience at Redcar leaves no doubt that the proportion of mill scrap in a furnace charge has a major bearing on the time between taps.

Sulphur in Raw Materials

With all orthodox open-hearth fuel practices, more sulphur is introduced into the furnace with the fuel than with the whole of the metallic charge. Whereas with producer gas about half the sulphur may be

Table I

MAGNET-CRANE OPERATION

Position of Wagons	Lifting Rate, lifts/hr.	Weight of Lift, cwt. Range	Weight of Lift, cwt. Mean	Loading Rate, tons/hr.
Medium Bought Scrap				
Opposite furnace charging	66·3	3·5–11·9	6·1	20·2
Opposite next furnace	50·7			15·5
Mill Crops				
Opposite furnace charging	60·0	20·0–26·0	23·0	69·0

absorbed in the gas checkers by lime dust, etc., all the sulphur in the oil enters the melting chamber. The relative weights of sulphur introduced into the furnace by the metals, fluxes, and fuel are as follows:

Material Charged	Sulphur Content, %	Sulphur Input, lb.
Iron, 65 tons	0·06	87·4
Scrap, 30 tons	0·06	40·3
Lime, 4·5 tons	0·25	25·2
Stone, 5·3 tons	0·05	6·0
Spar, 0·5 tons	1·50	16·8
Oil, 10 tons	2·50	560·0
Producer gas of same B.Th.U. input, assuming 50% desulphurization in checkers	...	187·0

The amount of sulphur absorbed by the charge from the fuel will depend on the atmospheric conditions in the furnace and, unless combustion is rapid, there will be appreciable sulphur pick-up, particularly during the charging and melting period. Charging time, type of scrap, and charging technique are also influential factors.

A significant proportion of the sulphur is introduced with the lime; it is paradoxical that a material used for sulphur removal should contain four to five times as much sulphur as the metal being desulphurized.

Pre-Refinement of the Iron

The shortage of scrap has served to focus more attention on methods of achieving a greater degree of refinement of the iron before charging to the furnaces. Oxygen and air blowing, agitation in a reaction drum with appropriate chemical treatment, Bessemer–open-hearth duplexing, and soda-ash treatment are some of the methods that are either in use or in the process of development.

Although some of these processes offer possibilities of large increases in the production rate, the choice must be mainly influenced by economic factors. There are several methods which, though extremely efficient

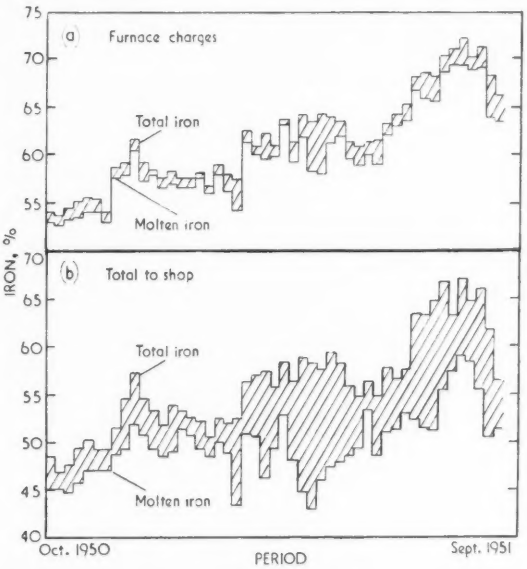


Fig. 2—Iron percentage

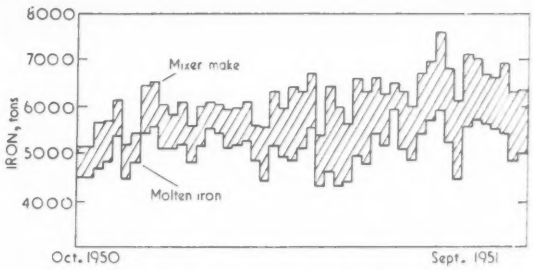


Fig. 3—Mixer metallic throughput

in the pilot stage, are as yet unsuitable for adoption where large tonnages of metal are to be handled.

Meanwhile, most hot-metal plants still rely on orthodox mixer practice and, with high percentages of metal, the mixer becomes the most important furnace in the shop.

At Redcar the mixer is of 350 tons capacity and, since 1947, has been oil-fired. When scrap was plentiful, the furnaces were charged with 50% of mixer iron and 50% of steel scrap, refinement being effected in the mixer by melting steel scrap and skulls in addition to oxides and fluxes. During 1951 it became necessary, owing to the scrap shortage, to increase the percentage of iron to the furnace progressively from 54% to 72% (*see* Fig. 2). The make of iron at the Redcar blast-furnaces was, however, inadequate to replace the loss of scrap, and the deficiency was made up with cold plate-iron, a quantity of which was available within the Company at that time.

Figure 3 is a record of the weekly mixer make and the weight of molten iron charged through the mixer during that year; the shaded area represents the cold metals, which consisted mainly of plate iron and steel skulls, the latter being the product of a vigorous recovery drive at the slag and ballast tips using mechanical diggers and magnetic separators.

The limited capacity of the mixer gave rise to some difficulty; since, during a typical period of 24 hr., 36 ladles of molten iron were charged, 32 ladles of metal teemed, several ladles of slag poured off, and 300 tons of cold metal charged and melted, controlled refinement of the iron was, at times, more desirable than practicable. Some degree of refinement was, however, achieved (*see* Fig. 4). The analyses indicate the removal of 27% of the silicon and 20% of the sulphur from the molten blast-furnace iron. The

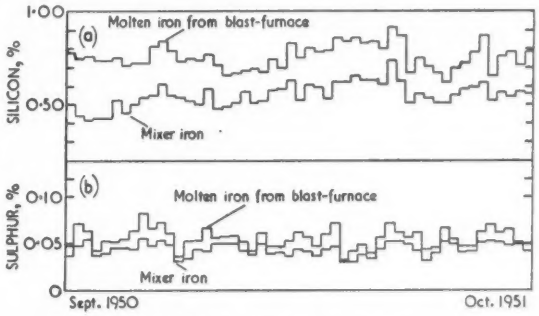


Fig. 4—Analysis of molten iron

analysis of the plate iron has been excluded, since this was variable and samples were not necessarily representative; its average quality was not, however, up to the standard of the molten iron. Under conditions of heavy cold-charging and increasing demands on the mixer, there were occasions when unpredictable fluctuations in the analysis of the molten iron to the furnaces led to hard or soft melts and melting slags of variable basicity.

Although mixer practice during this time may be considered to have deviated from the ideal, the performance of this furnace under difficult conditions gave grounds for some satisfaction, and it is felt that its conversion to oil-firing has been to a large extent justified. Oil-firing lends itself readily to thermal-input control, an important factor in successful mixer practice, particularly when demands are greater than those anticipated when the furnace was designed. A wider flexibility in burdening is made possible; a reduction in burden cost may be achieved by the heavy charging of steel skull and scrap when available, but on the other hand, when the hot-metal supply from the blast-furnaces is below requirements, the deficiency may be offset by the rapid melting of appreciable quantities of cold iron. In the latter case, however, the opportunity for controlled refinement is limited.

The consumption of refractories on the mixer since conversion to oil has been remarkably low. The first roof lasted for three years and the second roof is in its third year; repairs to port ends, uptakes, and slag pockets have been negligible; front and back linings have been repaired annually and, although all checkers have been taken out each year, most of the bricks have been cleaned and re-used. On no occasion has it been necessary to take the mixer off for major repairs between annual holiday shutdowns.

The average oil consumption on the mixer over the past two years was 5·1 gal./ton of mixer iron.

Slag Bulk

The greater slag bulk resulting from higher percentages of iron in the furnace charges inevitably affects the roof/slag/metal temperature differentials and hence the heat-transfer rate. When increases in metallurgical load are being discussed, it is usual to assess the quantitative effect of the difference in slag depth on slag surface temperature; such calculations are often based on the assumption that the density remains constant, and on this basis the change from 54% to 72% of iron in the charges at Redcar would mean an increase of 40% in the slag weight. Assuming a temperature gradient of 10° C./in., this would mean an increase of 18° C. in the slag surface temperature for a given metal temperature.

The assumption of constant slag density is, however, unwarranted, since high percentages of hot metal often promote a tendency towards increased porosity of the slag at a period in the charge when the rapid transfer of heat to the bath is essential, and, although the effect of slag weight on the heat transfer to the bath is considerable, the effect of density is even greater. Under certain circumstances a given weight of slag may be subject to a considerable increase in porosity, together with a corresponding increase in depth, and few steelmakers are fortunate enough to be unaware of the insulating properties of a foaming slag.

Foaming is a phenomenon associated with the surface tension rather than with the viscosity of the slag. During the period of foaming, the slag is not a true liquid but a series of small bubbles which, on rising to the surface, do not burst. The tendency for a slag to foam is affected by both chemical and physical factors. In the former category SiO_2 and Al_2O_3 are two of the worst offenders, and the adsorption of fine ore, etc., into the gas/liquid interface will tend to increase the stability of the foam.

Temperature, however, plays an important part, and unless the heat input during charging has been adequate and progressive, or if erratic charging causes steep temperature gradients throughout the charge, the tendency for the slag to foam will increase. Cold metal from the mixer, siliceous melting slags, and high-carbon melts are also contributory factors.

Once foaming has developed, the transfer of heat to the metal is negligible and the process of steelmaking is virtually suspended until the slag assumes its normal condition. The surface temperature of the slag rises and care is necessary to avoid damage to refractories. Excessive reduction of the fuel input at this stage will, however, prolong the foaming period, and the roof temperature must be maintained at the maximum safe-working limit if loss of production is to be minimized.

Such slags may be a major problem on furnaces using uncarburetted mixed gases or other fuels producing flames of low luminosity, but heavy foaming should be the exception rather than the rule on oil-fired furnaces with shallow baths, and such has been the case at Redcar with the hot-metal percentages so far experienced.

Hearth Area

The depth of a given volume of slag will vary inversely with the bath area, which is an important aspect of furnace design. The hearth area of the Redcar furnaces is 470 sq. ft., equivalent to 5·2 sq. ft./ton capacity, this figure being within the range considered to be optimum for furnaces of this capacity.

Although the bath area has an important bearing on the heat-transfer rate, the slag/metal interface area dominates the reaction rate, and it will be obvious that this area will be a function of bath agitation. Thus, with a briskly boiling bath the area of contact

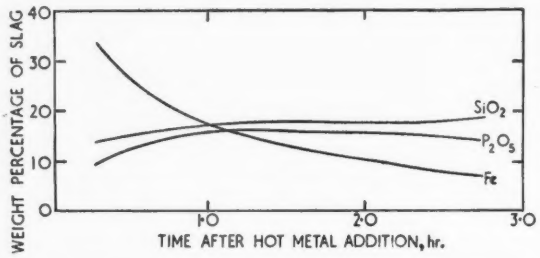


Fig. 5—Changes in slag analysis between charging and melting

between slag and metal will be considerably in excess of calculated values. In this respect frequent stirring with a rod is effective, the ebullition thus caused being much greater than would be expected from the mechanical action of stirring. A vigorous boil, promoted either by the normal carbon reaction or by the rod, will accelerate the slag/metal reaction, promote more efficient heat transfer with less refractory wear, and produce cleaner steel.

Flush Practice

To minimize the disadvantages of increasing slag bulk due to higher metal/scrap ratio (or poor iron), a more regular flush practice is necessary. Running slag off fixed furnaces is not wholly controllable, and some degree of compromise must be accepted. Flushing off at the most convenient opportunity from a physical standpoint does not necessarily give the greatest metallurgical advantage. For example, immediately after the addition of hot metal, when the surface of the bath is at a high level, the layer of slag is comparatively thin, and the bath is often in a state of such turbulence that any appreciable quantity of slag run off is usually accompanied by free iron, whereas later in the melting period the charge settles down and the opportunity of slagging may be lost.

Figure 5 shows typical curves obtained from the analyses of a series of slag samples, taken at intervals during the melting period of a number of charges; immediately after the hot-metal addition, the iron content is at its maximum and the percentages of SiO_2 and P_2O_5 are at a minimum. If all the factors are taken into consideration, it is probable that the optimum time for slagging is between 1 and 2 hr. after the furnace is full. The iron and manganese content of the flush slag is not a total loss, since the removal of appreciable quantities of P_2O_5 and SiO_2 results in a reduced weight of refining slag, and consequently a lower weight of iron and manganese in the slag run off after tapping.

Fuel Combustion

It has often been stated that an increase in the production rate of a furnace results in a reduction in the fuel consumption per ton of steel. Although this is often apparently true, it would, perhaps, be nearer the truth to say that the more fuel that is efficiently burned within the melting chamber, the higher will be the production rate. The efficient transfer of heat to the charge is the most important item in open-hearth steelmaking, and most of the other factors affecting furnace performance are either directly or indirectly associated with it.

The long rolling flame serves only to waste fuel and retard the production rate, and to avoid this the rapid mixing of an adequate quantity of preheated air is necessary. The first essentials are to promote early contact of air and fuel and to produce conditions that will facilitate intimate mixing. Many factors influence the mixing rate, but the most significant are the velocity of the fuel issuing from the port or burner and the angle of impingement of the air and fuel.

Fuel Velocity—When using producer gas, it is impracticable to attain high fuel velocity, in view of the difficulty in maintaining high gas pressure and the need to have a gas port of reasonable dimensions so as to effect proportional distribution of the waste gases through the checker system. With cold coke-oven gas the latter compromise is unnecessary, since only the air is to be preheated, and, as higher pressures can be maintained, there is more scope for burner design to produce the higher velocities that facilitate rapid mixing and flame direction. The use of atomized liquid fuels with coke-oven gas, in addition to increasing the luminosity of the flame, contributes in a large measure to the rapid entrainment of air for combustion.

With oil-firing, similar principles apply and the

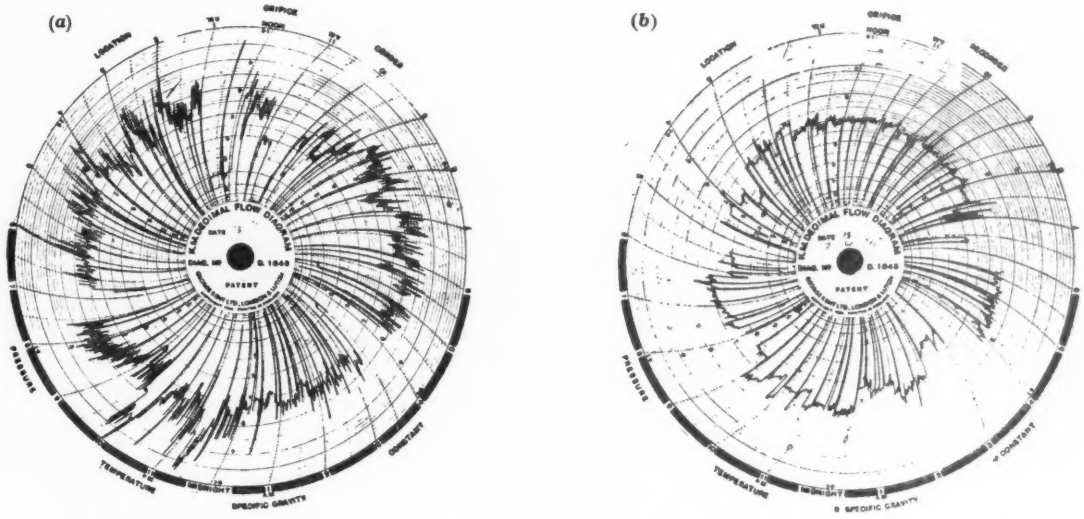


Fig. 6—Oil-flow charts showing (*a*) violent fluctuations when using ¾-in. burner tube, and (*b*) improvement after changing to 1-in. burner tube

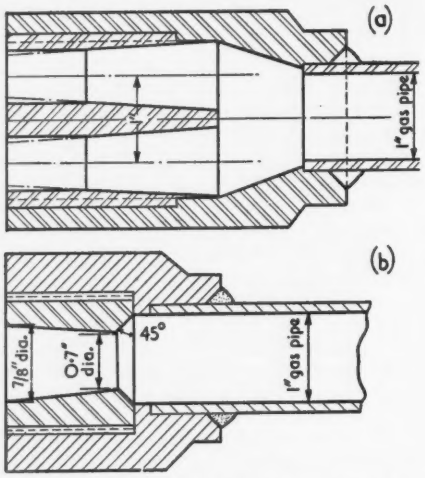


Fig. 7—Oil-burner nozzle blocks: (*a*) Twin-orifice; (*b*) Venturi or convergent–divergent nozzle

speed of combustion is largely influenced by the jet momentum of the atomized fuel stream. Increasing the steam/oil ratio promotes earlier combustion by reducing the droplet size and by increasing the velocity of the mixture issuing from the nozzle. The disadvantages of introducing large quantities of steam into the furnace are, however, obvious and any step that would promote early flame development with the minimum of steam would be in the right direction. Frictional losses in the burner tube should be kept to a minimum. The central tube of the original burner at Redcar was of $\frac{3}{4}$ in. dia. with an oval orifice at the tip, and back-pressure in this burner tended to promote 'hunting,' particularly at high flows; changes in the steam pressure resulted in fluctuations of the oil flow. Figure 6 shows a particularly bad case and the effect of increasing the diameter of the central tube to 1 in., a modification that has been applied to all burners at Redcar. The nose of the burner has been designed to accommodate a screwed-in nozzle plug, which facilitates experimentation with various nozzle designs on standard burners.

Figure 7*a* shows a twin-orifice burner designed to promote better mixing by providing a greater surface area for air entrainment. Figure 7*b* shows a convergent–divergent or Venturi-type nozzle that gives about 90% recovery of the pressure loss due to the restriction.

Experience at Redcar with three different types of back-end atomizer indicates that this factor is not of major importance. Tip atomization would be expected to be more efficient, but on several plants where trials have been made with both types, little difference in performance has been noted.

Angle of Impingement of Air and Fuel—The angle of impingement of air and fuel is a function of port design and, although there has been little radical change in the design of fixed open-hearth furnaces since the process was introduced, there have been numerous modifications, mainly attempts to improve port efficiency. The introduction of the Venturi and Maerz furnaces, which had as their object the more efficient mixing of air and fuel, met with some success and many of these furnaces are still giving excellent service. The Venturi port, although it allows a large angle of impingement, does not afford free access of air to the underside of the flame. This shortcoming does not apply to the single-uptake furnace, in which the air is introduced at an angle of more than 90° to the centre-line of the flame and has access to all sides of the fuel as it leaves the burner. Even more efficient mixing might be attained with a port-end incorporating the steep ramp of the Venturi furnace with a single uptake. This design has shown excellent results on small-scale models, but has not yet had a full-scale trial.

The position of the gun is a critical factor. The base of the flame after just clearing the table should be allowed to impinge on the bath at an acute angle, to avoid excessive 'spreading' with consequent damage to linings and roof near the skewbacks. The deposition of solid particles by recirculating gases is one of the many factors affecting roof wear, and localized erosion may be minimized to some extent by changing the direction of the burner, thus modifying the flow pattern.

The distance of the gun tip from the bath is also of major significance. Although it is essential for combustion to be complete before the gases reach the outgoing end, it is also vital that valuable heat should not be expended before the flame reaches the bath at the ingoing end. This applies particularly to single-uptake furnaces, where combustion is accelerated. The moderate success of furnaces where very large single uptakes have been introduced may have been due not only to aerodynamic instability but also to too early flame development and excessive heat release over the port end. On the single-uptake furnaces at Redcar, it has been found that the advancement of the guns across the uptake gives better results in spite of the extra water-cooling losses involved. The effects of water-cooling the burners of single- and twin-uptake furnaces can be seen from the following figures:

	Heat Loss, % of Total Heat Input	
	Ingoing End	Outgoing End
Single-uptake furnaces	0·90	1·26
Twin-uptake furnaces	0·28	0·39

Attempts have been made to reduce the heat lost to cooling water on the advanced guns by covering them with refractory material.

Although the single-uptake furnace cannot be

Table II

COMPARATIVE FURNACE PERFORMANCE OVER 12 MONTHS

Furnace		Average Weekly Production		Oil Consumption, gal./ton
		Tons	Cwt.	
K	Single-uptake	1631	4	24·06
J	Single-uptake	1613	17	24·15
H	Twin-uptake	1546	16	24·59
E	Twin-uptake	1459	2	25·58
B	Twin-uptake	1445	8	25·59
D	Twin-uptake	1439	0	25·75
A	Twin-uptake	1428	18	25·97
G	Twin-uptake	1428	17	26·08
C	Twin-uptake	1418	12	26·40
F	Twin-uptake	1416	2	26·48

considered an unqualified success, this design has shown to some advantage on the 90-ton furnaces at Redcar. Table II shows the average weekly production of individual furnaces during 12 months. In considering these figures, it should be borne in mind that the single-uptake furnaces *J* and *K*, owing to their position in the shop, take some preference in the allocation of mill scrap, and that the furnace crews are of a high standard.

Rapid combustion of the oil is necessary if sulphur pick-up is to be minimized, and the single-uptake furnaces have shown some advantage in this respect.

Air/Fuel Ratio

Having obtained the conditions conducive to rapid air entrainment, the next step is to decide the optimum air/fuel ratio, which is the subject of some controversy. One school of thought considers that a constant flow of air should be maintained throughout the charge, irrespective of any change in the fuel flow, but at Redcar the system of constant air/fuel ratio is preferred. The air/fuel ratio is manually controlled, the air-flow indicator being calibrated to read the same as the oil indicator when 10% excess air is being carried. Figure 8 is a frequency curve of weekly air/oil ratios during 12 months on a typical furnace.

With variable air input it is desirable that the pressure in the furnace should be under control. The most convenient point at which to measure the furnace pressure is at the crown of the roof, and to maintain atmospheric pressure at sill level to avoid infiltration of cold air it is necessary to allow for the buoyancy effect at working temperature when arriving at the optimum roof pressure, which, under Redcar conditions, is about 0·080 in. W.G. In the absence of furnace-pressure control, any reduction in fuel and air flow will result in the infiltration of cold air into the furnace. Without changing the oil and measured air flows, the waste-gas analysis can be varied by merely adjusting the furnace pressure (*see* Table III).

Where there are no means of controlling the furnace pressure, there is some justification for constant air flow, since, owing to the fact that with oil-firing the waste-gas volume is almost equal to the volume of air used for combustion, this serves to maintain a reasonably steady furnace pressure. Excess air can be used to advantage during heavy reaction (*e.g.*, after the addition of hot metal) to burn the CO evolved, but unless the furnace pressure is controllable this would result in excessive sting at the doors.

The measured volume of air is not necessarily equal to the air entering the furnace at the ports but, with correct roof pressure, there is probably a closer relationship than was once supposed.

No furnace should be without either manual or

Table III

VARIATION OF WASTE-GAS ANALYSIS BY ADJUSTMENT OF FURNACE PRESSURE

Oil Flow, gal./hr.	Air Flow, cu. ft./min.	Roof Pressure, in. W.G.	Waste-Gas Analysis, %		
			CO_2	O_2	CO
260	8240	0·053	12·0	6·6	Nil
260	8240	0·060	12·8	5·0	Nil
260	8240	0·074	13·8	3·9	Nil
260	8240	0·080	14·0	2·3	Nil
260	8240	0·090	14·8	0·7	0·7

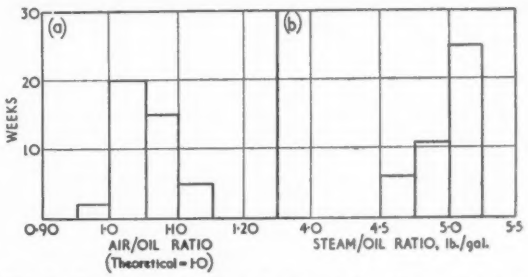


Fig. 8—Record of air/oil and steam/oil ratios on typical furnace

automatic means of controlling its pressure, and if the former method is used the controlling mechanism must be easy to operate. There must be sufficient draught available at the stack to compensate for increasing pressure losses through the boiler, valve, and checker systems, so that the optimum pressure may be maintained in the furnace throughout its campaign.

Heat Losses Due to Water-Cooling

Since the introduction of the open-hearth furnace, there has been a steady increase in the extent of the water-cooling of the furnace structure. Water-cooled members are now included on front and back linings, doors, door frames, roof skewbacks, lintels, ports and burners, tables, end walls, dampers, valves, and, in the case of tilting furnaces, end chills and port-end seals. Longer furnace life and availability and, with producer- and mixed-gas fired furnaces, better control of flame direction have justified the introduction of water-cooling, but the magnitude of the heat losses due to this factor raises the question of whether the time has come to call a halt.

At Redcar water-cooling is limited to door frames, oil burners, and tuyere coolers supporting the guns, and the mixer has, in addition, end chills and seals. Nevertheless, heat lost to the cooling water approaches 10% of the total heat input from the oil, and this is low compared with some plants, where water-cooling may account for 20–30% of the total heat input. Even a 10% loss would represent over 2*s*. per ton of ingot, excluding the cost of the water-cooling service and the cost of damage due to leaking pipes. Although some of the heat lost to water-cooling would, in any case, be lost by radiation, it must be borne in mind that, owing to the inherently low heat-efficiency of the open-hearth furnace, heat inputs higher than the measured values are necessary to compensate for the losses.

It must be accepted that to some extent water-cooling is advantageous and, indeed, essential in some parts of the furnace. Heat losses can, however, be minimized by protecting the water-cooled members with an adequate covering of refractory material and by maintaining this covering as far as possible throughout the furnace campaign.

Instrumentation and Control

During the period of intense development and the wider application of instruments to open-hearth furnaces, some rather extravagant claims about the

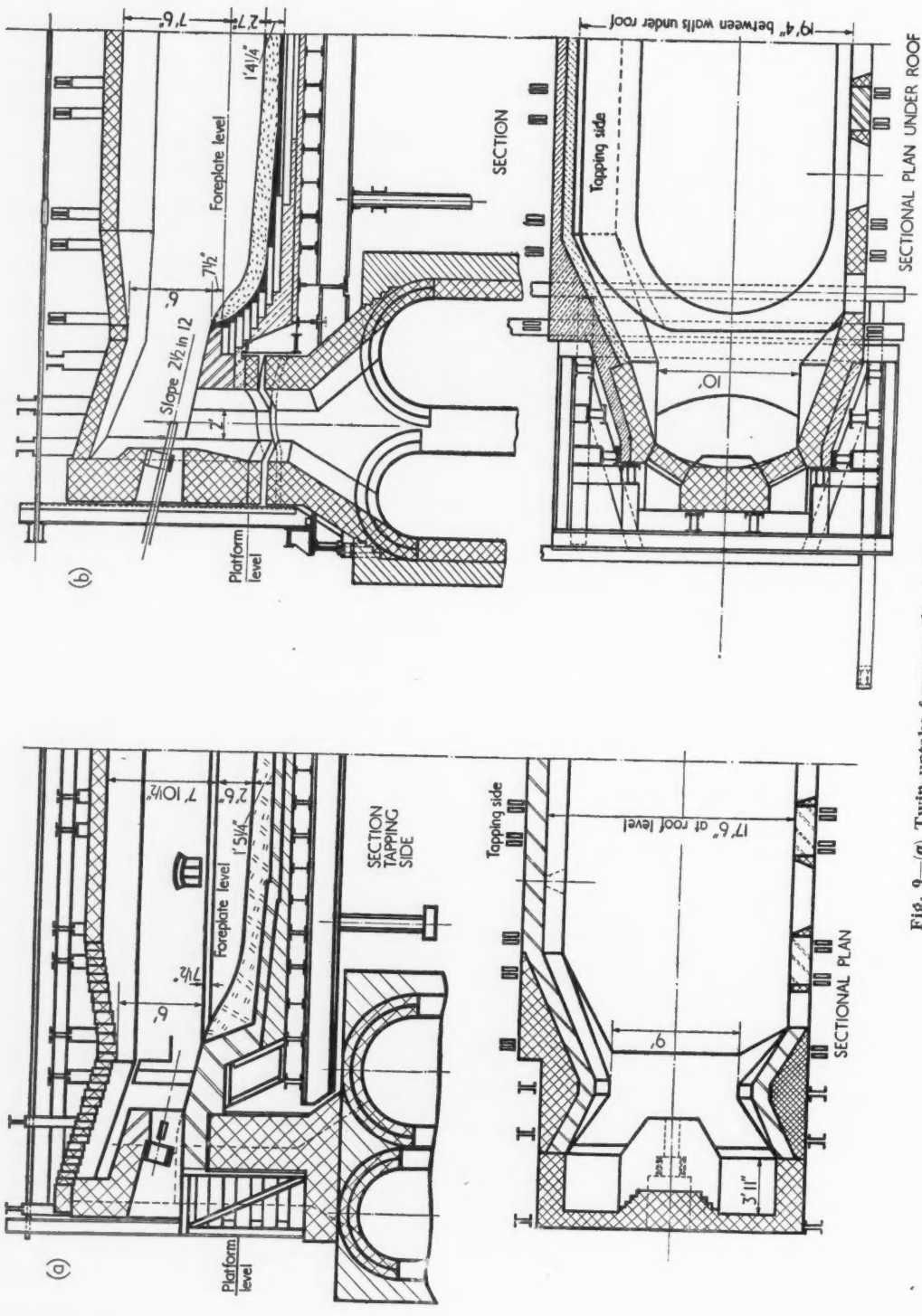


Fig. 9—(*a*) Twin-uptake furnace; (*b*) single-uptake furnace

benefits to be expected from extensive instrumentation led, naturally, to an attitude of scepticism on the part of many steelmakers.

Although these early flights of fancy have not been substantiated, there is little doubt that carefully selected instruments, chosen for their utilitarian rather than for their ornamental value, can be of enormous benefit to furnace operators. Fuel, air, and steam flowmeters have proved to be indispensable on oil-fired furnaces, and the measurement and control of furnace pressure is a decided asset. The roof-temperature pyrometer has caused most controversy, probably because of the many variables affecting its performance. Once its limitations are appreciated, however, it can be very useful, not only as a warning when the roof temperature approaches its safe-working limit, but also to give the melter confidence in maintaining optimum fuel inputs.

During the late refining period, the steel temperature should be the controlling factor. Whereas the safe roof temperature should not be exceeded, heat input in excess of that necessary to maintain the required steel temperature should be avoided. Too high a tapping temperature results in wastage of fuel, higher refractory wear, and reduction in mould life and can be a contributory cause of cracked ingots, whereas loss of yield and uncontrollable teeming conditions can result from low tapping temperature. Many plants have reported considerable improvements in these respects from the use of the immersion pyrometer.

Continuous measurement of oxygen in the waste gases leaving the melting chamber by making them actuate an air/fuel ratio controller would, together with a furnace-pressure stabilizer, provide an excellent means of controlling combustion (CO_2 measurement is of little use for this purpose, particularly in hot-metal shops).

EFFECT OF FURNACE DESIGN ON REFRACTORY WEAR

Roofs

The consumption of refractory materials is an appreciable item in the ingot conversion cost and this, in addition to the effect of refractory life on furnace availability, justifies any effort made, either in design or operation, to reduce wear without impairing productivity.

It is perhaps surprising that a process which is essentially basic should be operated in a furnace having a roof consisting of acid material. Although there have been during the past 15 years a number of trials with basic roofs, there is little evidence to show that the higher productivity and prolonged roof life fully compensate for the extra cost of the chrome–magnesite bricks and the elaborate suspension equipment, particularly as the fuel consumption is usually higher on the all-basic furnaces. Furthermore, chrome–magnesite bricks exhibit a bursting tendency due to iron-oxide absorption, and this results in spalling or flaking under conditions of fluctuating temperature. This could be a deciding factor against the basic roof on plants where fettling is performed with the fuel off.

Of the ten furnaces at Redcar, four have semi-sloping back walls (Fig. 9*a*) and of the remaining six (which have fully sloping back walls) three have been converted to the single-uptake design (Fig. 9*b*). That furnace design has its effect on roof wear is shown by the marked difference in the wear pattern on these furnaces (*see* Fig. 10). On the double-uptake furnaces, there is a localized ' gouging ' in the area adjacent to the back skew along the whole length of the furnace. In an effort to minimize this wear, back skews were lifted 9 in. and trials were made with low-alumina silica blocks, of low porosity, in the area of maximum wear. The results of these trials indicate that the judicious use of these more expensive bricks in vulnerable positions is fully justified.

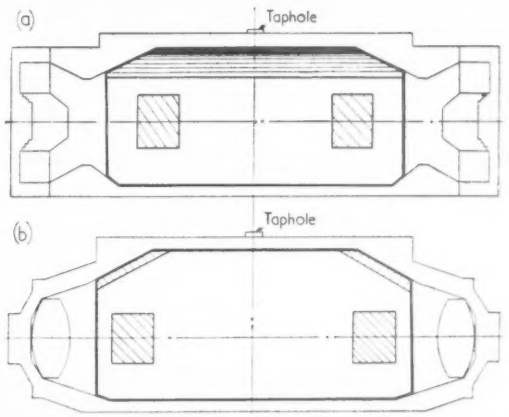


Fig. 10—Roof-wear patterns: (*a*) Twin-uptake furnace; (*b*) single-uptake furnace

The pattern of wear on the roofs of the single-uptake furnaces takes a different form, there being very little gouging along the back. There is, however, slightly heavier wear at the ends of the main roof, and super-duty blocks have been used to advantage in this area. The average roof lives since the introduction of the single-uptake furnaces were as follows:

Type of Furnace	Average Roof Life, heats	
	Actual	Net (after allowing for patches)
Single-uptake	369	327
Twin-uptake	305	273

Linings

The fully sloping-back linings consist of 9-in. chrome brick backed with 9-in. firebrick, and these are usually replaced only when the lower bank needs attention. In addition to reducing the cost of the lining, the firebrick serves to minimize heat losses.

The front linings on all furnaces are vertical and of the same design. Originally, the upper pillars were of silica, which reacted with the basic bricks beneath, so that after a short time the lower pillars were washed out. Although this was parged with chrome–magnesite paste, it was difficult to maintain a stable lining. Since replacing the silica in the pillars with chrome–magnesite, lining life has improved and less fettling trouble has been experienced on the front banks.

In one trial front lining installed, the pillars (in-

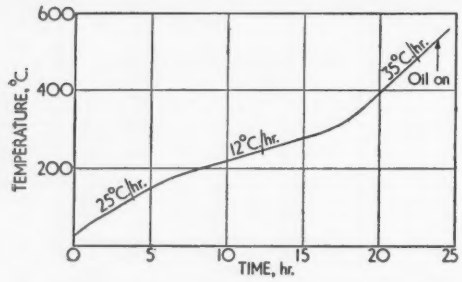


Fig. 11—Coke-oven gas preheating schedule after installing new bottom

cluding the jambs) consisted of chrome–magnesite bricks internally reinforced with steel mesh. This trial was not a success, the bricks splitting along the line of the mesh, but similar bricks have given excellent service in the sloping-back lining at another plant within the Company. Where trouble is experienced with front linings, the archless door is worthy of consideration. This design dispenses with the silica arch and facilitates the building of solid basic-brick pillars. A water-cooled lintel is necessary to protect the roof skewback channel over the door opening, but the heat losses due to this may be less than is the case where collapsed arches and jambs expose an inverted **U**-shaped cooler.

Front-lining wear on the single-uptake furnaces has been somewhat lighter than on the other furnaces. Uptake erosion has also been much less than was originally anticipated.

There is little doubt that furnace design, efficient combustion, and the shape and direction of the flame are factors that have an appreciable effect on the nature and degree of refractory wear.

Furnace Hearths

Furnace productivity is influenced to a large extent by the amount of time lost in fettling, and the construction and maintenance of the hearth are therefore of vital importance. The four most recent bottoms to be installed at Redcar have all been fully rammed, one with graphitized doloma and three with tarred graded doloma. All have proved reliable. The brickwork of the bottom consists of 4½-in. firebrick stepped up to give a surface approximately parallel to the finished hearth contour, followed by 3 in. × 3 in. courses of magnesite or stabilized dolomite bricks. An 8-ft. square panel in the taphole area consists entirely of magnesite. Preheating by coke-oven gas is controlled at 25° C./hr. up to 180° C., 12° C./hr. through the cristobalite inversion range, and 30–40° C./hr. above 310° C. (*see* Fig. 11). The period of preheating should be kept to a minimum, since the high proportion of water vapour in the products of combustion of coke-oven gas has a deleterious effect on the doloma. After firing with oil a pre-selected schedule is closely followed (*see* Fig. 12), and after slagging the furnace starts to charge about 70 hr. after firing.

Unsuitable size-grading of the doloma used for fettling can lead to a wastage of time and material, and this should therefore be controlled as closely as possible. A typical grading of the fettling material used at Redcar is as follows:

Size	%
+ ½ in.	5·0
½–¼ in.	24·0
¼ in.–7 mesh	45·0
7–25 mesh	20·0
25–72 mesh	3·0
Above 72 mesh	3·0
	100·0

INGOTS AND MOULDS

The Ingot

The term ' ingot quality ' is rather ambiguous, since it must be related to the purpose for which the product is intended, a good ingot being one which best meets this purpose. The factors affecting ingot quality are so numerous that even to list them would be beyond the scope of this paper.

Of the raw materials it may be said that the percentages of manganese and sulphur are of the greatest significance; the harmful effects of non-ferrous metals in the scrap will depend on the type of steel being made. Although some of the factors are not within the control of the steelplant, much can be done to promote conditions that increase the tendency towards good steel. A briskly boiling bath under a good basic slag, correct tapping temperature, clean taphole practice, appropriate deoxidation, and careful teeming into clean moulds are some of the required conditions.

Plates made from 0·20% C steels are more susceptible to fracture than the low-carbon grades. This is possibly due partly to the peritectic reaction at 1492° C., which results in a volume change and the evolution of heat, and which is at maximum intensity between 0·15% and 0·25% C. Furthermore, it has been shown by Hall* that the range below the solidus before the steel attains any appreciable ductility is widest at about 0·20% C. These factors are accentuated by the fact that it is usual to roll the heavier plates from casts within this range of carbon. The Mn/(C × S) ratio appears to have some significance, the tendency to fracture being lower when this factor approaches 80, and for the heavier plates some advantage has been gained by reducing the carbon, increasing the manganese, and keeping the sulphur as low as possible.

* H. F. Hall, Second Report of the Steel Castings Committee, Spec. Rep. No. 15, pp. 65–93: 1936, London, The Iron and Steel Institute.

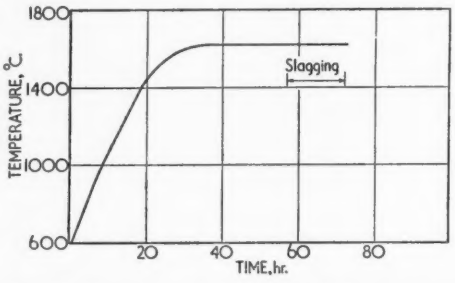


Fig. 12—Heating schedule after installing new bottom

The appearance of the ingot top gives an approximate indication of the structure, and to determine the type of balanced ingot that would produce the minimum of defective material in the Redcar mills, the percentage of defectives was plotted against the 'ingot top number,' an arbitrary figure indicative of the degree of rise of the ingot top during solidification (*see* Fig. 13). These figures were based on full casts and their usefulness is limited by the fact that no account is taken of variations within casts. There is, however, a tendency to add excess aluminium to the first ingot to provide against excessive rise should the oxygen content be higher than normal, and this sometimes results in the first ingot (about 10% of the cast) being over-deoxidized. A reliable assessment of the concentration of oxygen in the bath is therefore desirable. The FeO content of the slag and the carbon in the metal are useful, though not always infallible, guides, and direct chemical estimation is apparently not yet suitable for routine application.

The reactive oxygen at any time during the charge may, however, be calculated from the carbon concentration and the rate of carbon drop.*

Figure 14 illustrates the application of the method to a typical charge. There is reasonable correlation between calculated oxygen and the behaviour of the steel in the moulds, but in view of the changes in oxygen content between furnace and ingot, more work is required in this direction before the method can be applied with confidence.

Mould Consumption

The high price of hematite castings justifies any effort to reduce the consumption of ingot moulds per ton of steel. Teeming temperature and technique, tap-to-strip times, and mould/ingot weight ratio are some of the factors affecting this item.

* I. M. Mackenzie, *J. Iron Steel Inst.*, 1946, No. 2, pp. 55P–59P.

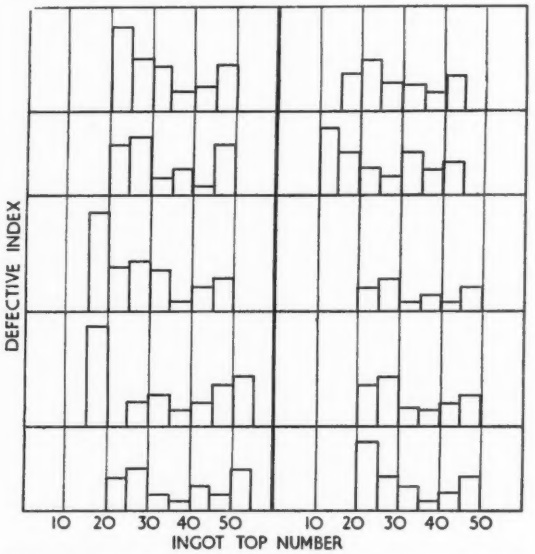
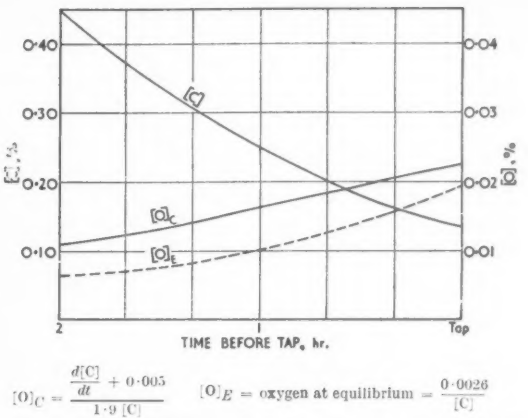


Fig. 13—Relation between ingot top structure and defective plates



$$[O]_C = \frac{\frac{d[C]}{dt} + 0{\cdot}005}{1{\cdot}9\,[C]} \qquad [O]_E = \text{oxygen at equilibrium} = \frac{0{\cdot}0026}{[C]}$$

Fig. 14—Oxygen calculated from carbon concentration and rate of carbon drop on typical charge

There is little doubt that mould lives are directly influenced by the length of time the ingots are allowed to stand in the moulds before stripping, and appreciable improvements in mould consumption have been obtained at Redcar by reducing this time. There is the additional advantage of heat conservation by shortening the track time.

The relationship between mould and ingot weight also has an important bearing on the mould consumption per ton of steel. For each type of ingot and teeming practice, there is an optimum mould/ingot ratio, above which mould iron will be used uneconomically, and in many existing moulds this ratio may be too high. The results of trials at Redcar with 10-ton moulds of lower ratio than the standard were as follows:

	Ingot Weight, cwt.	Mould Weight, cwt.	Mould/Ingot Ratio	Mean Life	Mould Consumption, lb./ton of steel
A	203	232	1·14	96·1	26·6
B	203	186	0·92	118·1	17·4

A reduction of 35% in mould consumption was achieved without any apparent effect on ingot quality. Although they may have been affected to some extent by trial conditions, the results are sufficiently encouraging to warrant further trials.

HUMAN FACTORS

The Skill of the Melter

Of the major factors affecting furnace performance, that which receives the least attention in the literature is the degree of skill of the melter. Although this variable is difficult to measure, the difference in the performance of a furnace having a first-class team and a similar furnace manned by a crew of less than average ability is so great as to warrant some consideration. The degree of skill of a melter is not necessarily related to the length of his experience, and the wide variation in individual ability may be to some extent a reflection on a rather haphazard system of training.

A good melter is a craftsman of the highest order, whose main assets throughout his career have been a capacity for hard work, a keen interest in the process, a fund of common sense, a keen eye, and an

ability to correlate cause and effect. There is, however, another factor that has influenced his progress: he has probably served his apprenticeship with good melters who have been able and willing to give him the benefit of their experience and skill.

All prospective melters will naturally not possess the inherent characteristics that are the foundation of the complete craftsman and, as in other trades and professions, it is inevitable that there will always be differences in proficiency. Nevertheless, a young furnaceman will be influenced by the guidance he receives from the senior men on his furnace, and it is possible for a potentially good youngster to be set on the wrong track by doubtful advice. Can anything be done to make his training less fortuitous? Operatives courses, such as those conducted by the City and Guilds Institute, and membership of technical institutions are useful in that they promote a wider interest in the industry. The primary need is, however, for reliable guidance (while doing the job) on such practical aspects as the diagnosis of the condition of the slag from its appearance, the correct way to take a sample or repair a taphole, the recognition of the optimum type of flame required at different periods of the charge, and the correct timing of the feed; *i.e.*, the type of advice imparted by a first-class melter to the members of his crew who are keen enough to learn. Although the problem presents some difficulties, its solution would pay handsome dividends.

Interdepartmental Co-operation

A steelplant is not an independent unit, and its success will be influenced to a large extent by the efficiency and co-operation of maintenance and technical departments. 'Co-operation' becomes a meaningless word unless it is applied in more than one direction, and every effort must be made from within the steelplant to give the Engineering and Electrical Departments the opportunity of maintaining the equipment in efficient running order. Although this may at times be difficult, particularly under continuous working conditions, to postpone urgent repairs can only result in deterioration of plant and more serious delays at a later date.

Acknowledgments

The author thanks Mr. A. MacLeod, Director and General Manager of Dorman, Long and Co., Ltd., for permission to publish this paper. He also expresses his appreciation of the helpful co-operation of his colleagues at Redcar Works.

LETTER TO THE EDITOR

STABILITY OF THE SO-CALLED DELTA-FERRITE PHASE IN AUSTENITIC STEELS

The existence of a proportion of a body-centred cubic ferromagnetic phase in many austenitic steels at room temperature is well known, and, as it has commonly been supposed that this phase remains relatively unchanged from room temperature up to the solidus, it has often been termed δ-ferrite by analogy with the δ-phase in pure iron.

In many austenitic steels, ferromagnetism may be induced or increased by cold work, owing to the production of a body-centred phase by transformation of metastable austenite. It has always been assumed that, on heating such cold-worked steels to a temperature sufficient to transform the 'martensite' back to austenite, the effects of the cold-working would be removed completely.

Work carried out recently shows that neither of the above suppositions is true.

Several chromium–nickel austenitic steels, including 18/8/Ti, 18/8/Nb (both cast and wrought), 18/8/Mo/Ti, and the valve steel *XCR* (0·5% C, 24% Cr, 5% Ni, 2·5% Mo), have been examined in a high-temperature X-ray camera. In all these steels the presence of a body-centred cubic (B.C.C.) phase was readily shown at temperatures up to 600° C. At higher temperatures the lines due to the B.C.C. lattice became weaker, and they were no longer detectable at a temperature varying from 750° to 1000° C. according to the steel. On cooling to room temperature the B.C.C. lines reappeared, and thus the disappearance of these lines was not due to transformation of the ferrite to sigma. Usually it was found that the B.C.C. lines were faint on first cooling to room temperature, but on standing for a few days they would attain their original intensity.

Of particular interest was the valve steel *XCR* examined by Cina in a different connection,[1] as it had a higher ferrite content than the other steels examined by us. After annealing at 1050° C. this steel contains approximately equal quantities of austenite and ferrite, with much carbide. The high-temperature X-ray camera showed the B.C.C. content to fall progressively from 650° C. to only a trace at 940° C. At the same time, the austenite (F.C.C.) lines became stronger, but showed no change in parameter, although the lines were never very sharp. There were no new lines produced. On cooling down, 'moderately strong' B.C.C. lines were evident after 1 hr.; after 60 hr. they had become 'very strong' and the F.C.C. lines had become weaker.

These results demonstrate that the body-centred cubic phase in these duplex austenitic steels is not stable at temperatures in the region of 900° C. but transforms to a face-centred cubic phase. Now it is known that annealing these steels at temperatures greater than about 1000° C. causes an increase in the proportion of ferrite found by any method after the steel is quenched or air-cooled, and the ferrite shows no signs under the microscope of having been formed from the austenite matrix during cooling. It therefore appears that, when hot, two F.C.C. phases are present, one of which transforms to the B.C.C. ferrite on cooling whilst the other is stable. There is no fundamental reason why an alloy should not contain two phases of different composition but the same lattice type. In iron–nickel–chromium alloys, the lattice parameter is not very sensitive to composition, because of the similar sizes of the three atomic species, and thus the failure to distinguish the two F.C.C. phases in the X-ray camera is understandable. The most remarkable

features are the speed with which the change takes place, and the growth of the ferrite content at room temperature. This formation of ferrite at room temperature was observed by Bowen and Hoar[2] in work on sigma in 18/8/Mo/Ti.

No ferrite was observed in 18/8/Ti at 1100° C., and it is reasonable to question whether a high-temperature B.C.C. phase exists in any of these steels. The equipment available did not permit examination at temperatures above 1100° C.

A number of cold-worked specimens of plain 18/8 steel were also examined in the high-temperature camera. At temperatures up to 600° C. a high proportion of B.C.C. 'martensite' was present, but at 650° C. this disappeared completely and the austenite lines became stronger. Cold-worked 18/8/Ti behaved in a similar manner. On cooling, the B.C.C. lines reappeared. The effect of cold-working was not permanently removed until the specimens were heated to 850° C. The reversible transformation of the martensite is not easy to explain, since the F.C.C. phase to which it transforms would be expected to be identical with the original austenite and thus completely stable on cooling. A possible explanation is that the cold-working ejects carbides from the lattice, and since these carbides do not redissolve at 650° C., the F.C.C. phase formed from the martensite at that temperature has a composition different from that of the original austenite and less stable.

A wide field for further work would thus appear to have been opened, and this note is published in the hope of attracting other workers to the subject. Major factors for investigation include the nature of the transformation, whether isothermal or spread over a range of temperature, whether it can be detected by other means, and whether any delta-ferrite is produced on heating these complex steels to very high temperatures.

J. Brown
D. Clark
W. D. Clark

Imperial Chemical Industries Ltd.,
Billingham Division,
Co. Durham.

1. B. Cina: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 229–237.
2. K. W. J. Bowen and T. P. Hoar: Proceedings of the First World Metallurgical Congress, 1951, pp. 695–706: 1952, Cleveland, Ohio, American Society for Metals.

Further Correspondence on the Paper—

THE STRESS-CORROSION CRACKING OF MILD STEELS IN NITRATE SOLUTION*

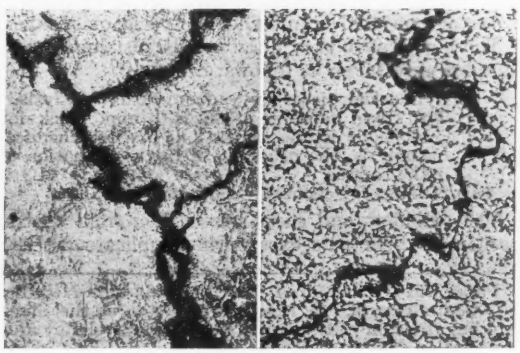
By R. N. Parkins

Monsieur **E. Herzog** (S.A. des Hauts-Fourneaux, Forges et Aciéries de Pompey) wrote: When reading Dr. Parkins' reply to my correspondence[1] on his paper, I felt that some of my views were not clearly explained.

The decomposition of ferrite saturated with carbon and nitrogen cannot give an anodic phase with a high carbon content. Both the iron carbide and the iron nitride are cathodic in opposition to iron.

Diebold[2] has measured a maximum e.m.f. of 0·2 V. in neutral solutions of sulphate or chloride (pH = 7). In acid (pH = 2–6) or basic (pH = 8–11) solutions the e.m.f. decreases to about 0·10 V. A cell constituted by nitrided low-carbon steel and bare steel in calcium- or ammonium-nitrate solutions gives an e.m.f. of 0·2–0·3 V. at 100° C.[3]

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 149–162.



	C, %	Mn, %	Si, %	P, %	S, %	Mo, %	Cr, %	Va, %
A.	0·30	0·68	0·28	0·020	0·012	0·32	1·08	...
B.	0·12	1·44	0·12	0·016	0·022	...	...	0·075

Fig. A— × 250 **Fig. B— × 500**

When ferrite is saturated with carbon it undergoes decomposition by yielding and slip. This process is accelerated at 100–120° C., the testing temperature. It is reasonable to assume that precipitation of finely dispersed carbides (cathodic phase) takes place along grain boundaries (submicroscopic size) or in slip bands. From the work of Whitwham and Evans[4] on corrosion fatigue, an anodic shift of the potential may be expected during slip in the disarrayed ferrite lattice.

It must also be emphasized that ferrite–cementite structures are more sensitive to notch-effect and prone to micro-cracks during straining in some preferential plane transverse to the direction of rolling. Intergranular deposit of cementite favour local stress-peaks, and it seems that the bond between iron and this kind of cementite is looser than the strong bond between cementite and ferrite in pearlite aggregates.

I agree with Dr. Parkins that this picture is a very rough one and cannot account for all the facts observed, but these views were useful in detecting steels that were resistant to stress-corrosion cracking in nitrates.

As an example of intergranular stress-corrosion cracking in an oil-well atmosphere high in H_2S (18%), a micrograph of a Cr–Mo steel treated to a U.T.S. of 100 kg./sq. mm. is shown in Fig. *A*. According to the experimental work of my co-workers Monsieur Camus and Monsieur Chentre, laboratory tests in a moist H_2S atmosphere with low-alloyed or plain-carbon steels produced almost intergranular stress-corrosion cracking, as shown in Fig. *B*.

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Studies in the Deoxidation of Iron

DEOXIDATION BY TITANIUM

By E. Ll. Evans, B.Sc., and

H. A. Sloman, M.A., F.R.I.C., F.I.M.

SYNOPSIS

This paper describes the preparation, analysis, and microscopical examination of a series of ingots made by adding oxygen and titanium in various amounts to 400-g. melts of pure iron. The analyses reported include the total oxygen and titanium contents of the ingots, and the chemical and X-ray analyses of the non-metallic inclusions isolated by alcoholic iodine extraction. The principal deoxidation product, *i.e.*, the substance found in iron containing a residual excess of titanium, is α-Ti_2O_3. As the proportions of titanium and oxygen change progressively from excess titanium to excess oxygen, the compounds found in the inclusions tend to occur in the following order: α-Ti_2O_3, Ti_3O_5, TiO_2, ilmenite ($FeO \cdot TiO_2$), a spinel which is termed a titanian magnetite, and Fe_2O_4. The series presumably ends with FeO, although no evidence of its existence was obtained. The oxide TiO was also found in some ingots containing an excess of titanium.

Previous similar work on compounds in the Fe–O–Ti system is reviewed briefly, and comparison shows that the colour of oxide inclusions containing titanium is an unreliable guide to their identity; for instance, inclusions of α-Ti_2O_3, reported previously to be deep violet, are found in the present work to be brown.

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THIS paper describes a continuation of a study of methods of analysis and identification of the products formed when molten iron–oxygen alloys are deoxidized by the addition of a suitable element—in this case, titanium. Earlier work dealt with the deoxidation products of aluminium,[1] manganese,[2] and silicon.[3]

The methods used for the production, analysis, and examination of samples of iron deoxidized by titanium were substantially the same as those used in the earlier work and discussed most fully in the paper on deoxidation by aluminium.[1]

PREPARATION AND SAMPLING OF THE INGOTS

The iron used in this investigation was prepared at the National Physical Laboratory from electrolytic iron sheet by the method described by Hopkins, Jenkins, and Stone.[4] The compositions, expressed in wt.-%, of the two separate batches of iron prepared for the work were as follows:

	54*AF*1	54*AF*2
Carbon	0·002$_4$	0·002
Silicon	0·002	0·002
Sulphur	0·002	0·002
Phosphorus	0·004	0·003
Manganese	<0·005	<0·005
Nickel	0·003	0·003
Chromium	<0·001	<0·001
Copper	0·015	0·015
Aluminium	0·002	0·002
Oxygen	0·001$_5$	0·001$_3$
Nitrogen	0·001	0·001
Hydrogen	nil	nil

Oxygen was added as ferric oxide (Fe_2O_3) to melts of approximately 400 g. of this iron. The titanium used was in the form of sponge metal containing about 99·7% of titanium (major impurities: Fe, 0·2–0·3%; Mg, 0·035%; Si, 0·025%; C, 0·05%). In general the additions were made with the iron at a temperature not higher than 50° C. above its melting point, but in the preparation of four of the ingots (*TA*, *TG*, *TL*, *TM*) the temperature was raised a further 150–200° C., so as to break down bridges of solid iron which had been formed after the melting of the lower portion of the charge.

A microscopical examination of complete half-sections of two of the ingots to which large initial additions of titanium had been made revealed considerable segregation of inclusions into groups. There was, however, no systematic gross segregation in the sense that inclusions had become concentrated at the centre or near the outer surfaces of the ingots, except for the layer of 1–2 mm. thickness nearest to the top. This meant that apart from rejecting the top 5-mm. layer of the ingot no further steps could be taken to smooth out variations in concentration between the various portions taken for analysis. The surfaces of the ingots were filed heavily to remove adhering refractory material or any other superficial oxide layer.

The ingots were then quartered longitudinally and samples were taken as follows:

(i) Cylindrical pieces for vacuum-fusion analysis
(ii) Two 10-g. samples of slices 1 mm. thick for alcoholic iodine extraction: one for chemical analysis, the other for X-ray examination of the residue
(iii) Millings for chemical analysis of titanium.

The cylinders and slices were taken from central positions in the ingots, except when duplicate analyses

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Mr. Evans and Mr. Sloman are on the staff of the Metallurgy Division of the National Physical Laboratory, Teddington.

were made. In these instances, samples were taken from the upper and lower portions. Most milled samples were taken from complete longitudinal sections of the ingots, but those from ingots *TG* and *TQ* were taken from the upper and lower ends.

ANALYSIS OF THE INGOTS

The results of the various analyses of the ingots are summarized in Table I. The non-metallic (oxide) constituents were isolated from samples of the ingots by alcoholic iodine extraction at 65° C. The residues were analysed gravimetrically.

An estimate was made of the total oxygen contents of the samples by assuming that the iron in the residues was derived from FeO and the titanium from Ti_2O_3. Absolute values for the oxygen contents of other samples taken from the ingots were determined by the vacuum-fusion method. The total amounts of titanium in the ingots were determined by a colorimetric method. The titanium contents of the oxide residues were subtracted from the total titanium concentrations to give approximate values for the free metallic titanium contents of the ingots. In Table I the ingots have been lettered and tabulated, for convenience, in decreasing order of metallic titanium content.

The only oxides other than those of iron and titanium present in the alcoholic iodine residues were alumina and silica. These were not determined in a number of residues, as they were found to form a very small proportion of the total oxide contents. In ingots *TG*, *TK*, *TL*, and *TQ*, aluminium was determined using the same milled samples as for total titanium. The results show good agreement with the aluminium contents of the residues.

In the last column of Table I, values are given for the weight percentage of iron in the total of iron and titanium found in the alcoholic iodine residues. This value, which is fairly constant at about 4 for metallic titanium contents between 0·1 and 0·4 wt.-%, increases sharply as the metallic titanium contents decrease below 0·05%. In this particular relationship the ingots, with two exceptions (*TE* and *TQ*), fall into good order. It would be permissible to place ingot *TQ* before *TM*, in view of the possible error in deriving the metallic titanium content, but it is retained at the end of the Table in consideration of its X-ray analysis (*see* Table II).

The segregation of inclusions observed microscopically is manifest in the discrepancies in a number of the duplicate alcoholic iodine analyses and between the values for the oxygen contents derived by the two different methods. It should be understood that this segregation is present largely as a result of the melting procedure. This was deliberately contrived to retain a high proportion of the deoxidation products in the body of the metal for convenience in examination. Such a method involves rapid cooling and solidification of the metal after the introduction of titanium. The imperfect mixing which results was accentuated in this research by the combination of the low density and high melting point of the titanium and by its tendency to wet and creep over the surface of the crucibles. There was evidence in a few of the melts that some of the titanium had remained on the surface. Another factor contributing to the discrepancies in the analyses, of course, is the tendency of the deoxidation products to float upwards and become concentrated in the upper part of the ingots. In view of these considerations, the analytical results should be taken merely as a broad indication of the alloy compositions with which the various inclusions are associated. For the same reason, the quantities of titanium and oxygen initially added must not be taken to provide quantitative deoxidation data.

X-RAY EXAMINATION OF THE INCLUSIONS

The inclusions contained in samples of the ingots were extracted by the alcoholic iodine method, at 30° C. The residues were washed off the filter paper, and Debye–Scherrer powder photographs of samples were taken in a 19-cm. dia. camera. Cobalt Kα radiation was used in preference to that of copper, as the greater diffraction angles obtained with the former more than offset the disadvantage of the higher proportion of scattered 'background' radiation.

The results obtained from these X-ray analyses are summarized in Table II. They show primarily that when iron is deoxidized by an excess of titanium the product is α-Ti_2O_3. As the stoichiometric balance between titanium and oxygen proceeds through a very small excess of titanium towards an excess of oxygen, the deoxidation products in the ingots are found in the order α-Ti_2O_3, Ti_3O_5, TiO_2 (rutile), $FeO.TiO_2$ (ilmenite), a spinel, and magnetite. The figures given in Table II are an indication of relative quantities present, on the basis of only a visual estimate of the total radiation from each constituent. Most of the constituents were identified by comparing the patterns obtained with data listed in the A.S.T.M. Index of X-ray diffraction data* and in papers referred to in that Index. Some further information was found in a paper by Ehrlich[5] on compounds of oxygen and titanium. Ehrlich's paper does not contain numerical values for line spacings and intensities, but it includes a small-scale graphical representation of the X-ray patterns and the relative intensities of the lines.

The substances identified are considered in detail as follows:

α-Ti_2O_3—The spacings of the lines given by this compound were in agreement with those in the A.S.T.M. Index. Three additional lines, of spacings 3·7Å. (strong), 1·29Å. (medium), and 1·27Å. (medium), occurred together with the α-Ti_2O_3 patterns given by the residues from ingots *TA* to *TE*, and are noted as '*x*' in Table II. They are combined with the α-Ti_2O_3 lines to give the 'greater than 90%' assessment. Two of these lines, 3·7Å. and 1·29Å., are included by Ehrlich in his α-Ti_2O_3 pattern. It cannot be stated with certainty that these lines are absent from the other patterns containing α-Ti_2O_3.

TiO—This appeared in the residue from ingot *TG*, together with α-Ti_2O_3, the compounds being in an approximate ratio of 1:4. The pattern of this compound cannot readily be distinguished from that of

* Published jointly by the American Society for Testing Materials, the American Crystallographic Association, and the Institute of Physics.

Table I

RESULTS OF CHEMICAL ANALYSES OF INGOTS OF IRON DEOXIDIZED BY TITANIUM

Ingot	Additions to the Melt, wt.-%		Chemical Analysis of Alcoholic Iodine Residues, wt.-% of ingot sample									Total Oxygen, wt.-%		Total Ti (Chemical Method), wt.-%	Metallic Ti, wt.-%	Total Al (Chemical Method), wt.-%	Ratio 100 Fe/(Fe + Ti) in Residue
			SiO_2		Al_2O_3		FeO			Ti	Oxygen as Ti_2O_3	Alcoholic Iodine Residue	Vacuum Fusion				
	O_2	Ti	Oxide	Oxygen	Oxide	Oxygen	Oxide	Iron	Oxygen								
TA Top	0·05	0·45	0·0006	0·0003	0·0011	0·0005	0·0028	0·0022	0·0006	0·067	0·033	0·035	0·031	0·43	0·36	n.d.	3·2
Bottom			0·0005	0·0002	n.d.	...	0·0029	0·0023	0·0006	0·059	0·029	0·031			0·37		3·8
TB Top	0·05	0·40	0·0022	0·0010	0·0015	0·0007	0·0068	0·0053	0·0015	0·079	0·039	0·042	0·037	0·35	0·27	n.d.	6·3
Bottom			0·0002	0·0001	n.d.	...	0·0022	0·0017	0·0005	0·043	0·022	0·024			0·31		3·8
TC Top	0·1	0·40	0·0010	0·0005	0·0018	0·0008	0·0040	0·0031	0·0009	0·093	0·047	0·049	0·038	0·36	0·27	n.d.	3·2
Bottom			0·0004	0·0002	n.d.	...	0·0040	0·0031	0·0009	0·062	0·031	0·034			0·30		4·8
TD Top	0·05	0·32	0·0011	0·0005	0·0021	0·0010	0·0048	0·0037	0·0011	0·100	0·050	0·053	0·048	0·33	0·23	n.d.	3·5
Bottom			0·0002	0·0001	n.d.	...	0·0028	0·0022	0·0006	0·055	0·027	0·030			0·28		3·9
TE Top	0·05	0·45*	0·0009	0·0004	0·0026	0·0012	0·0087	0·0068	0·0019	0·065	0·033	0·036	0·019	0·32	0·25	n.d.	9·4
Bottom			0·0009	0·0004	n.d.	...	0·0074	0·0058	0·0016	0·055	0·027	0·032			0·26		9·6
TF Top	0·1	0·2	0·0009	0·0004	0·0018	0·0008	0·0036	0·0028	0·0008	0·108	0·054	0·056	0·017	0·20	0·09	n.d.	2·5
Bottom			0·0006	0·0003	n.d.	...	0·0029	0·0023	0·0006	0·053	0·027	0·029			0·15		4·1
TG Top	0·05	0·17	n.d.	...	0·003	0·001	0·0045	0·0035	0·0010	0·079	0·039	0·041	0·054	0·20	0·12	0·006	4·2
Bottom			n.d.	...	0·003	0·001	0·0050	0·0039	0·0011	0·030	0·015	0·017	0·008	0·08	0·05	0·003	12
TH Top	0·05	0·10	0·0033	0·0015	0·0034	0·0016	0·0041	0·0032	0·0009	0·102	0·051	0·055	0·016	0·10	...	n.d.	3·0
Bottom			0·0011	0·0005	n.d.	...	0·0039	0·0030	0·0009	0·038	0·019	0·024			0·06		7·3
TJ Top	0·1	0·05	0·0006	0·0003	0·0016	0·0007	0·0022	0·0017	0·0005	0·022	0·011	0·012	0·010	0·05	0·03	n.d.	7·2
Bottom			0·0005	0·0002	n.d.	...	0·0017	0·0013	0·0004	0·017	0·008	0·010			0·03		7·1
TK	0·034	0·065	n.d.	...	0·0018	0·0008	0·0073	0·0057	0·0016	0·052	0·026	0·028	0·012	0·067	0·015	0·003	10
TL	0·037	0·07	n.d.	...	0·002	0·001	0·0088	0·0069	0·0019	0·049	0·025	0·028	0·048	0·062	0·013	0·002	12
TM Top	0·1	0·2†	0·0023	0·0011	0·0019	0·0009	0·106	0·083	0·023	0·074	0·037	0·062	0·034	0·06	...	n.d.	53
Bottom			0·0011	0·0005	n.d.	...	0·087	0·067	0·020	0·021	0·011	0·032			0·04		76
TN	0·1	0·07	0·0016	0·0007	0·0012	0·0006	0·163	0·127	0·036	0·020	0·010	0·047	n.d.	0·040	0·020	n.d.	87
TP	0·1	0·05	0·0020	0·0009	0·0024	0·0010	0·188	0·146	0·042	0·018	0·009	0·053	n.d.	0·025	0·006	n.d.	83
TQ Top	0·005	0·1‡	n.d.	...	0·0013	0·0006	0·029	0·023	0·0064	0·032	0·016	0·023	0·093	0·044	0·012	0·002	45
Bottom			n.d.	...	0·0013	0·0006	0·028	0·022	0·0062	0·026	0·013	0·020	0·079	0·027	0·001	0·002	46

n.d. = Not determined.

* Capsule containing titanium adhered, half melted, to the lid of the crucible.
† Evidence of loss of titanium.
‡ Air leak into the system developed during the additions.

TiN, which might conceivably be formed if air leaked into the furnace during preparation of the alloy. To check this possibility, the nitrogen content of this ingot was determined. It was found to be 0·002 wt.-% (very similar to the content of the other ingots of the series), and this amount is too small to account for the quantity of constituent observed. The formation of TiO may be connected in some way with the high temperature at which the titanium addition was made to this particular melt.

Ti_3O_5—In the X-ray powder photograph of the residue from ingot *TF*, a distinct pattern was obtained, in addition to that of α-Ti_2O_3, which did not appear in any of the others in the series. After microscopical examination, an alcoholic iodine extraction was carried out on a 4-mm. slice from the top of the ingot. The X-ray picture of the residue consisted almost entirely of the unknown pattern. Comparison of the spacings and intensities of the lines with Ehrlich's data suggested that the compound might be Ti_3O_5. In a recent paper, Rusakov and Zhdanov[6] have given the lattice parameters of this compound (anosovite) but no data on the X-ray diffraction pattern. Calculation of the spacings of all the possible lines, however, gave values corresponding to all the lines observed in the pattern, as follows:

Observed Spacings (approx.), Å.	Calculated Spacings, Å.
3·47 strong	3·48
2·16 medium–strong	2·15
2·08 medium	2·10
1·91 medium–weak	1·92
1·88 medium	1·88
1·62 weak	1·64

It seems reasonable to suppose that the compound observed is indeed Ti_3O_5.

TiO_2 (Rutile)—This compound predominated in residues from ingots *TK* and *TL*. The spacings do not, however, correspond exactly with the various values given in the A.S.T.M. Index, and it seems reasonable to suppose that the rutile is not of its normal stoichiometric composition.

$FeO.TiO_2$ (Ilmenite)—This forms a large proportion of the residue obtained from ingot *TM*. The pattern conforms with that recorded in the A.S.T.M. Index.

Spinel—A spinel found to occur in residues from ingots *TM*, *TN*, *TP*, and *TQ* has a lattice parameter $a_0 = 8·43$–$8·44$ Å., whilst the relative intensities of the lines in its pattern are very similar to those of magnetite. The reported parameters of the latter range from $a_0 = 8·37$ to 8·41 Å., although only the value 8·37 Å. has been observed in all instances in which magnetite has been extracted from iron by the authors. There are two recorded spinels formed by iron and titanium oxides: $FeO.Ti_2O_3$ reported by Halla[7] as having a parameter $a_0 = 8·47$ Å., and the more usual, inversed, spinel $2FeO.TiO_2$ stated by Barth and Posnjak[8] to have a parameter $a_0 = 8·50$ Å. The relative intensities of the lines in the patterns of these spinels differ from those of magnetite.

The explanation of the identity of this spinel which first springs to mind is that it is a solid solution of an iron-titanate spinel in magnetite. This hypothesis does not, however, readily explain why the spinel occurs with the same lattice parameter and so presumably with the same composition in four different ingots. In two of these, *TN* and *TP*, the spinel is practically the sole inclusion constituent, and the ratio of iron to titanium is of the same order in both. In ingot *TM*, however, the spinel occurs with ilmenite, and in *TQ* with magnetite and apparently

Table II

X-RAY ANALYSIS OF CRYSTALLINE CONSTITUENTS OF ALCOHOLIC IODINE RESIDUES FROM INGOTS OF IRON DEOXIDIZED BY TITANIUM

Figures denote estimated percentages of total diffraction

Ingot	TiO	α-Ti_2O_3	Ti_3O_5	TiO_2 Rutile	$FeO.TiO_3$ Ilmenite	(Titanian Magnetite ?) Spinel	Fe_3O_4 Magnetite	'x'	Remarks
TA	...	>90	...	...	...	...	...	Present	
TB	...	>90	...	...	...	...	...	Present	
TC	...	>90	...	...	...	...	...	Present	
TD	...	>90	...	...	...	...	...	Present	
TE	...	>90	...	...	...	...	...	Present	
TF	...	60	40	...	...	...	...	...	
TG	20	80	...	...	...	...	...	...	
TH	...	50	...	...	...	...	...	...	A number of lines, totalling about 50% of the total diffraction, unidentified
TJ	...	75	...	...	...	...	...	...	Unidentified lines totalling roughly 25% of the total diffraction
TK	...	...	...	60	...	...	...	...	A medium proportion of unidentified lines
TL	...	...	...	80	...	...	...	...	Small proportion unidentified
TM	...	...	...	...	60	40	...	...	
TN	...	...	...	...	...	>90	...	...	
TP	...	...	...	...	...	>90	...	...	
TQ	...	...	...	...	...	60	20	...	About 20% unidentified, including apparently another spinel of parameter intermediate between those of the two spinels identified

Note: The figures given in the Table are an indication of the relative quantities of the various constituents present, on the basis of only a visual estimate of the total radiation from each constituent.

a third compound of spinel structure. For convenience we shall refer to this spinel of apparently fixed composition as titanian magnetite.

Unidentified Constituents—As will be seen from Table II, the residues from five of the ingots (*TH*, *TJ*, *TK*, *TL*, and *TQ*) contained appreciable proportions of unidentified constituents other than the substance '*x*' associated with α-Ti_2O_3. The spacings and relative intensities of these lines were noted, and it was found that there was no pattern common to any two of them. It is suggested that these constituents are associated with the presence of unintentional impurities (particularly silicon and aluminium oxides). It is thought justifiable to ignore their presence, as there is no evidence that they radically affect the inclusions typical of the ternary system Fe–O–Ti, although they could possibly be the cause of small variations in the parameters of, say, the spinels.

MICROSCOPICAL EXAMINATION

Polished unetched sections from all ingots were examined under the microscope. Visual examination was carried out with illumination from a tungsten-filament lamp passed through a Chance 0*B*9 'daylight correction' filter. Photographs were taken, all at a magnification of × 1000, using green monochromatic illumination from a mercury arc except in photographing Fig. 5, when violet illumination was used to accentuate the yellow constituent.

Attention was paid to inclusions that were characteristic of a given section. The inclusions illustrated may thus be regarded as typical, except that for convenience they are generally larger than the average.

The inclusions in ingots *TA* to *TE*, which may be assumed to consist almost entirely of α-Ti_2O_3, are globular or irregular in shape. Those illustrated in Figs. 1 and 2 are typical in size, shape, and concentration of those inclusions which are rather highly aggregated into clusters. Where they are more dispersed they tend to assume a spherical form. The colour was found to vary between a dark beige and chocolate. It was noted that the variation in colour was accentuated when the incident light was polarized, and rotation of the polarizer often resulted in interchange of colours of neighbouring globules. By this means also it was shown that most of the irregular inclusions consisted of partly coalesced monocrystalline globules. This feature, although visible to the eye, was not easily photographed, but it is shown most clearly in Fig. 5 for which a blue light source was employed. The variations in colour observed in the absence of the polarizing filter probably resulted from partial polarization by the glass slip used to deflect light on to the surface of the section.

In ingot *TF*, which according to the X-ray evidence probably contains Ti_3O_5 as well as α-Ti_2O_3, the inclusions were generally of similar form and colour to those described above. A large proportion, however, showed parallel bands of the two shades of brown, beige and chocolate. Some inclusions of circular section also showed straight-edged bands of very dark brown. These features appeared accentuated in the very high concentration of inclusions near the top surface of the ingot. Figure 3 shows a large inclusion, nearly spherical, which consists of a number of separate crystals. Suspended in it are numerous particles of iron. The photograph was obtained with ordinary illumination, and illustrates the rather small difference in shade between the browns. Figure 4 was obtained with crossed polarizer and analyser, and with a half-wave plate interposed between the specimen and analyser. The banding, which appears as if due to a twinning effect, and the variation in reflectivity due to the anisotropic nature of the crystalline material, are much accentuated.

A pale-yellow constituent was observed in ingots *TE* and *TG*. From the X-ray evidence for ingot *TG* this substance is presumed to be TiO. In ingot *TE* it appears in massive cubic form around a few of the inclusions. These are illustrated in Fig. 5, which was photographed with deep-blue illumination from a mercury arc. In ingot *TG*, however, the same constituent appears only as a fringe, rarely more than 0·001 mm. wide, around most of the brown α-Ti_2O_3 inclusions (Fig. 6). Its cubic habit is, however, discernible.

The inclusions in ingots *TK* and *TL*, consisting basically of rutile (TiO_2), are spherical and very dark grey, and generally contain numerous fine iron particles. Observation under plane polarized illumination shows that the material is birefringent and that the larger inclusions, at least, are polycrystalline (Fig. 7). The birefringence is shown by the fact that the various crystals become dark and light relative to each other as the polarizing filter or the specimen is rotated.

No precise distinction could be drawn between the types of inclusion observed in sections of ingots *TM*, *TN*, *TP*, and *TQ*, even though two sections taken from central positions in each ingot were examined. In each section all inclusions were roughly circular in section. In ingot *TM* (ilmenite + spinel) the inclusions appeared to consist of from one to many grey-brown globules, sometimes in a small amount of grey matrix. Neither constituent appeared anisotropic (Figs. 8 and 9). Inclusions in ingot *TN* (spinel) were largely grey-brown and contained iron particles and irregular dark pieces (Figs. 10 and 11). There was a suggestion that the dark particles had collected at crystal interfaces (Fig. 10). Alcoholic iodine residues from ingots *TN* and *TP* contained the same spinel material. The inclusions differed, however; those in ingot *TP* were a brownish dark-grey in colour, and contained much dark-coloured dispersed matter (Fig. 12). The main constituent was polycrystalline and appeared anisotropic. The demarcation between the grains was not so distinct as in the rutile-containing inclusions of ingot *TN*, and no clear photographic record was obtained of the birefringence.

The inclusions in ingot *TQ* (principally spinel and magnetite) consisted of grey-brown idiomorphs in a light-grey matrix (Fig. 13).

DISCUSSION

In the process of deoxidation, reaction takes place in molten iron between the dissolved titanium and oxygen until an equilibrium is attained between the residual titanium and oxygen and the product of deoxidation. On solidification and cooling of the iron, further reaction occurs as a result of the shift in equilibrium. A measure of the total extent to which

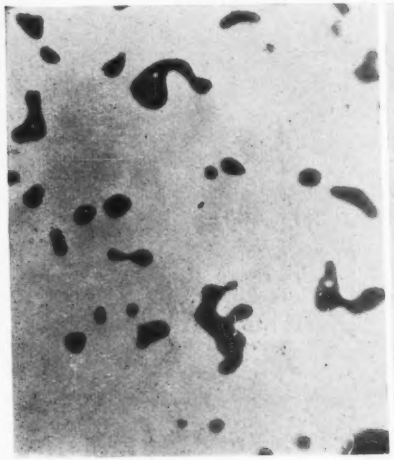

Fig. 1—Ingot *TB*

Fig. 2—Ingot *TD*

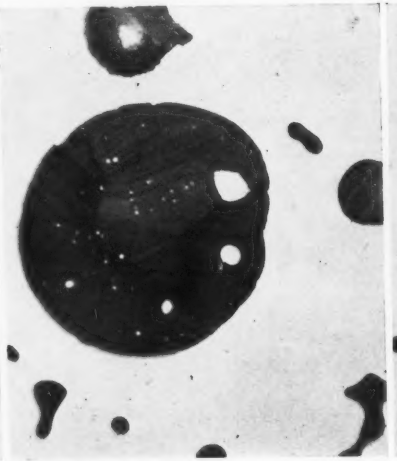

Fig. 3—Ingot *TF*

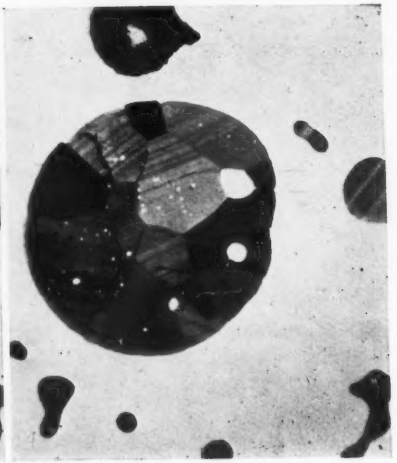

Fig. 4—Ingot *TF*. Crossed polarizers with interposed half-wave plate

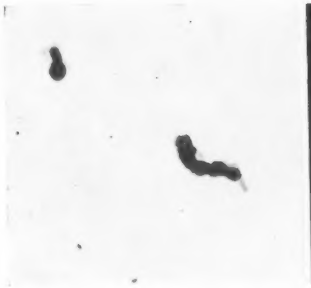

Fig. 5—Ingot *TE*. Blue filter

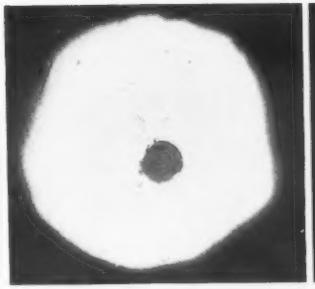

Fig. 6—Ingot *TG*

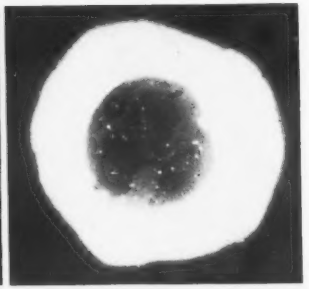

Fig. 7—Ingot *TK*. Polarized illumination

Figs. 1-13—Inclusions in ingots × **1000**

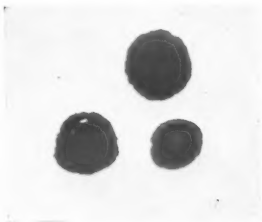

Fig. 8—Ingot *TM*

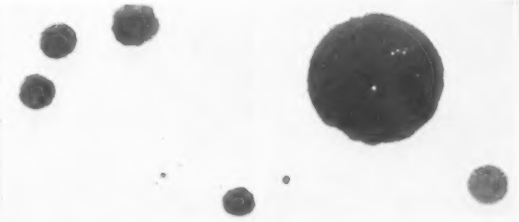

Fig. 9—Ingot *TM*

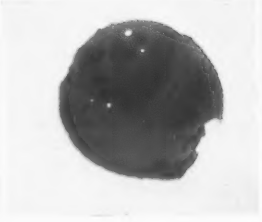

Fig. 10—Ingot *TN*

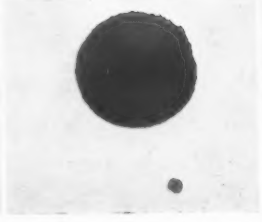

Fig. 11—Ingot *TN*

Fig. 12—Ingot *TP*

Fig. 13—Ingot *TQ*

the deoxidation reaction takes place is given by the analyses of metallic titanium and of oxygen as iron oxide in the cooled ingots. These are plotted in Fig. 14.

The deoxidation products found in the solidified ingots at room temperatures have either been formed in the crystalline state in the molten metal or have crystallized in globules which were molten at the freezing point of the iron. They are not necessarily of the same composition as those in equilibrium with the molten iron alloys, but at the same time they are not likely to depart very much from these compositions. We can therefore postulate, from a study of Fig. 14 and Table II, the approximate ranges of melt compositions that will contain on solidification the various deoxidation products. When iron is deoxidized by titanium in sufficient quantity to leave an excess of 0·2% or more titanium, the product formed is α-Ti_2O_3, possibly together with some TiO. This is in agreement with the results of a study by Wentrup and Hieber[9] of equilibria in the deoxidation of iron by titanium. Within this range the oxygen content may be determined precisely by the alcoholic iodine method. The residual oxygen as iron oxide is low, generally below 0·002%. As the metallic titanium content of the iron decreases below 0·2%, while remaining in excess of the oxygen present, the deoxidation product tends to contain higher oxides of titanium, *i.e.*, Ti_3O_5 and TiO_2. Over this composition range, the alcoholic iodine method will not yield an accurate figure for the oxygen content of the sample extracted, so long as the oxides cannot be determined separately.

When the iron has been deoxidized by titanium but is left with a surplus of oxygen, the non-metallic inclusions consist of combined oxides of iron and titanium, including ilmenite and a spinel, in the order of increasing oxygen content of the iron.

The oxygen combined with titanium in those irons which contain no excess of titanium over oxygen may be assumed, for calculation, to occur as TiO_2. Even if the spinel phase does contain titanium not combined as TiO_2 (*cf.* $2FeO.TiO_2$), any errors resulting from this assessment will be small in comparison with the total oxygen.

A feature which is found in the present work and which is common to the deoxidation products of aluminium, silicon, and titanium is that a surplus of iron oxide associated with a combined oxide of the deoxidizing element and of iron tends to form magnetite, Fe_3O_4. So long as this cannot conveniently be determined chemically, there is a possibility of a 20% deficiency in that part of the oxygen content determined on the assumption that it is present as FeO.

In the results presented in Table I, errors between the oxygen contents determined by the alcoholic-iodine and vacuum-fusion methods, due to the assumption for the former method of the wrong oxides, are small compared with the variations between samples due to segregation.

A striking feature of the present work is that it shows clearly that deoxidation products in iron do not necessarily occur as compounds identical in appearance and colour with their pure counterparts. Wentrup and Hieber accounted for the products of deoxidation by titanium in terms of a simplified

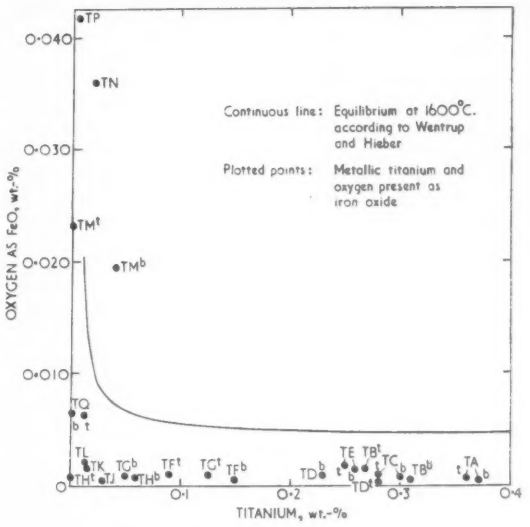

Fig. 14—Deoxidation of iron by titanium

system involving Fe, FeO, $2FeO.TiO_2$, $FeO.TiO_2$, Ti_2O_3, and Fe_2Ti. They deduced that Ti_2O_3 was the only titanium oxide present since they did not observe the white and light-bronze colours stated by Ehrlich[5] to be characteristic of stoichiometrically pure TiO_2 and TiO respectively. It may be true that, under the particular conditions of solidification and cooling imposed on their ingots by Wentrup and Hieber, these oxides were not formed, although they do appear in the ingots now under discussion. The main deoxidation product observed by Wentrup and Hieber, which must undoubtedly be Ti_2O_3, was dark violet in colour, in agreement with Ehrlich's description. The brown colour of the α-Ti_2O_3 observed in the present work might be due, according to Ehrlich, to a deficiency in oxygen. However, the same colour is found even when the Ti_2O_3 is associated with Ti_3O_5. In these circumstances, Ti_2O_3 would not be expected to be deficient in oxygen.

The anosovite, Ti_3O_5, in ingot *TF* eludes precise identification under the microscope. The very dark bands observed in some of the inclusions may be due to this compound (Ehrlich reports compositions in the range $TiO_{1·6}$ to $TiO_{1·73}$ to be blue-black), but they are in a very small proportion compared with that of Ti_3O_5 in the alcoholic iodine residue. There is almost certainly some connection between the presence of Ti_3O_5 and the large amount of banding in the inclusions, which otherwise appear in colour very much like Ti_2O_3.

The colour and lattice parameter of the rutile in ingots *TK* and *TL* both differ from those recorded for the pure compound. There are two possible reasons. One is that the Ti/O ratio in the rutile departs somewhat from its ideal stoichiometric value. Ehrlich reports $TiO_{1·97}$ to be dark blue, even though TiO_2 is white or colourless. It is not possible to check the change in the X-ray pattern accurately enough with Ehrlich's published data. The other possible reason

is that the rutile lattice may contain iron oxide. Ferrian rutile, which occurs naturally, contains a proportion of Fe_2O_3 and is dark in colour.[10] The circumstances in which the inclusions are formed in iron may well produce such a departure from the composition of pure rutile. The presence of metallic iron in the rutile inclusions suggests that, on first precipitation, their composition was intermediate between that of a pure titanium oxide and ilmenite, separation of iron having taken place on cooling. The same appeared to have occurred, but to a lesser extent, with the inclusions containing anosovite, and suggests that a smoother continuity exists in the liquid deoxidation products than is shown by the series of crystalline compounds formed.

The ilmenite in ingot *TM* has not been distinguished from the spinel phase under the microscope, although its X-ray pattern agrees with that of the pure substance. The colour of ilmenite is reported to range between red and black.

The composition of the spinel in ingots *TN*, *TP*, and *TQ* has been discussed, and the phase termed, for convenience, titanian magnetite. The results of the present work do not exclude the possibility that the stoichiometrically simple spinel $2FeO.TiO_2$ can occur as a deoxidation product, but they do show that the range of possible inclusion compositions between this spinel and iron oxide involves something more complex than the simple binary eutectic system postulated by Wentrup and Hieber. The titanian magnetite of fixed composition may be an end member of a solid-solution range, but there is no proof of this.

The occurrence of a small proportion of aluminium oxide in all the residues should not be overlooked, as it may have contributed slightly to the observed departures of some of the compounds from their properties in the pure form.

The titanium–oxygen equilibrium in molten iron in contact with a slag at 1600° C. has been determined experimentally by Wentrup and Hieber. Richardson[11] has demonstrated the difficulties inherent in calculating the limits of deoxidation by titanium under conditions of equilibrium with the various products. In a calculation of equilibrium with TiO_2, he obtained deoxidation limits well below those determined by Wentrup and Hieber, which suggested that the activity coefficients of titanium in iron and of oxygen in iron–titanium alloys are well below unity. No attempt is made, therefore, in this paper to calculate the limits of titanium and oxygen contents of iron in equilibrium with the various deoxidation products. Neither the activity coefficients of oxygen and titanium in iron, nor the partial free energy of solution or combination of oxygen with the slag phase, is known with sufficient accuracy to give any significance to such a calculation. Ideal or regular behaviour cannot be assumed for melts containing iron and titanium oxides, and theoretical considerations are further complicated by the stable existence over relatively wide ranges of composition of some of the titanium oxides.

CONCLUSIONS

The principal product of deoxidation of iron by titanium, which occurs in inclusions when the residual titanium exceeds about 0·2 wt.-%, is α-Ti_2O_3, with which may sometimes be associated a little TiO. As the excess of titanium decreases, higher oxides of titanium are found, notably anosovite, Ti_3O_5, and rutile, TiO_2. As the proportion of titanium to oxygen changes from that of excess titanium to excess oxygen, the overall compositions of the inclusions change accordingly, the compounds found ranging from titanium oxide to ilmenite, an iron-oxide–titanium-oxide spinel, and magnetite. The complete series presumably ends with wüstite, although no evidence of this was obtained. These compounds may be found either alone or more generally as mixtures, the inclusions being duplex in appearance.

Comparison of the microscopical appearance of the inclusions formed in this work with other descriptions of similar compounds suggests that inclusions of titanium oxide or of mixed titanium and iron oxides can be identified positively only by X-ray crystallographical methods, since small departures from stoichiometric compositions can result in a radical change in colour.

No difficulty has been observed in extracting inclusions of titanium oxide or of mixed titanium and iron oxides by the alcoholic iodine method. Where metallic titanium is in excess, the oxygen associated with the titanium in the residues may be calculated on the basis of its occurrence as Ti_2O_3. Where an excess of metallic titanium is not present, much of the oxygen may be combined with titanium in the residue as TiO_2, and no great error is introduced by assuming that it does occur in this form, at least when no other alloying element is present.

Acknowledgments

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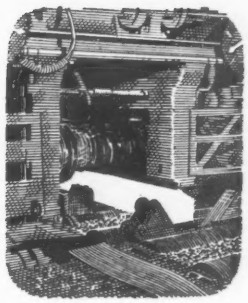
Effect of Composition on the Warm-Working Characteristics of Austenitic Alloys



By G. T. Harris, M.A., F.Inst.P., and H. C. Child, B.Sc., A.I.M.

SYNOPSIS

The creep and rupture strength of many austenitic alloys may be improved by a solution treatment near the solidus temperature of the alloy, followed by stamping or otherwise deforming the alloy in the temperature range 600–800° C. Such a process has been termed 'warm-working.'

The effect of the composition of the base, and of various additions of carbon and the carbide-forming elements tungsten, molybdenum, vanadium, niobium, and titanium, on the warm-working characteristics of austenitic nickel–cobalt–iron–chromium alloys has been investigated. Cobalt-rich bases with 0.25–0.5% of carbon and a total of about 9% of carbide-forming elements are most suitable for this process. The best alloys have a 300-hr. rupture strength at 750° C. of 19 tons/sq.in. 775

Introduction

It has been known for some years that the creep and rupture strength of many austenitic heat-resisting alloys can be improved by a 'warm-working' treatment.[1, 2] This process consists of working the solution-treated alloy in the temperature range 600–800° C. by hammering, stamping, rolling, etc. The solution treatment of such an alloy is normally carried out at temperatures within 100° C. of the solidus. It is found that temperatures of this order are necessary to attain solution of the various carbides present in these alloys and that the maximum benefit from 'warm-working' can be obtained only when adequate solution of the precipitating phases has been achieved. The alloy may be either air-cooled or oil- or water-quenched from the solution temperature.

The optimum warm-working conditions are dependent on the subsequent service or test conditions. In general, the lower the service or test temperature the higher is the optimum value of the warm-working reduction. The effect of warm-working temperature is not pronounced for most alloys within the range 600–800° C., lower temperatures tending to be the more suitable.

It has been found that about 5% reduction in thickness at 700° C. is a suitable treatment for austenitic alloys to be used at 750–800° C. The gas-turbine disc alloy *G18B* has been processed in this manner with considerable success,[3] and, apart from an improvement in the creep and rupture properties at high temperature, the proof stress at room temperatures was also raised substantially.

An earlier paper[4] has described the development of a Ni–Co–Fe–Cr austenitic alloy strengthened by the addition of carbide-forming elements to promote precipitation hardening. For the most part, the alloys of that investigation were tested in the solution-treated condition. It was considered that a determination of the high-temperature properties of some of the many alloys of the systematic series of that investigation in the warm-worked condition would yield valuable information. The type of alloy that is most suited to the warm-working process would be revealed and, if any of the better alloys were substantially improved, a material suited for the highest-duty gas-turbine rotor blades would result.

EXPERIMENTAL PROCEDURE

All the alloys were melted in a 15-lb. high-frequency furnace, cast into 2-in. ingots, and hammer-cogged to ½-in. sq. bars. A standard treatment was used throughout most of the investigation. This consisted of two stages:

(i) Air-cooling from 1280° C. after soaking for 2–3 min.

(ii) Hammering between flat tools at 700° C. to a 5% reduction in thickness.

Small-creep-unit tests[5] were carried out at fixed stresses at 750° C. and in some cases at 800° C. No extensometers were used, the creep strain being determined by the deflection of the loading beam.

For convenience the investigation is divided into three parts:

(*a*) Effect of the base composition

(*b*) Effect of carbon and carbide-forming elements*

(*c*) Further tests with modified heat-treatments.

The first section deals with the effect of systematic chromium variations and of variations of the Ni : Co : Fe ratio of the alloy base; the second section gives the effect of the total percentage and relative proportions of the carbide-forming elements (W, Mo, Nb, V, and Ti) and the carbon content of the alloy, and the

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* For convenience, chromium is considered as an element of the base and not as a carbide-forming element. This is not, of course, technically correct.

Table I

CREEP CURVES AT 750° C. OF TWO TYPICAL ALLOYS IN THE SOLUTION-TREATED AND THE WARM-WORKED STATES

	C, %	Mn, %	Si, %	Ni, %	Co, %	Cr, %	Mo, %	V, %	Nb, %
A	0·29	0·82	0·49	20·2	20·6	20·1	2·73	3·02	3·08
B	0·50	0·76	0·35	15·2	40·0	19·0	2·93	2·70	1·86

Alloy	Heat-Treatment	Stress, tons/sq. in.	Time, hr., to: 0·5% Creep Strain	1% Creep Strain	2% Creep Strain	5% Creep Strain	Fracture	Minimum Creep Rate, $\times 10^5$ per hr.	Elongation at Fracture, %	Q = Fracture Time as Warm-Worked / Fracture Time as Solution-Treated
A	N. 1280° C.	12	3	10	27	41	42	59	8	7·4
	N. 1280° C. Warm-worked 5% at 700° C.	12	160	309	...	...	310	1·3	4	
B	N. 1280° C.	14	5	20	501	...	502	1·1	3	0·6
	N. 1280° C. Warm-worked 4% at 700° C.	14	130	288	...	...	288	1·7	1	

third section shows the effect of modified heat-treatments on a selection of the more promising alloys.

GENERAL EFFECT OF WARM-WORKING

Warm-working may affect different alloys in very different ways. The results of creep tests under fixed conditions on solution-treated and on warm-worked materials, reported in Table I, exemplify this.

Alloy *A* is a type of material that is well suited for the warm-working process. Both the creep and rupture strengths are improved. Alloy *B*, however, is typical of the class of alloys whose creep strength* is improved but whose rupture strength may even be diminished.

The ratio Q of the fracture time of the warm-worked material to that of the solution-treated material at the same stress and temperature is considered to be the best measure of the suitability of alloys for this process. Alloys can invariably be improved in creep strength by warm-working, but rupture strength is improved only with particular alloys. Where Q is less than 1 the alloy is regarded as 'over-warm-worked,' as a smaller reduction during working would not have diminished the rupture strength to the same extent. The ideal alloy should obviously not 'over-work' at moderate reductions, as such an alloy would be difficult to process commercially. Alloy *B* has been 'over-worked,' and this may be connected with the fact that a low elongation of only 3% was found in the rupture test on the solution-treated material.

It is considered that the ductility of an alloy at the warm-working temperature is one of the most important factors in determining its suitability for warm-working. An alloy of low ductility might reasonably be expected to develop cracks on a micro- or macro-scale, which would impair the rupture strength. The only available measure of the ductility of these alloys is the elongation at fracture in short-time rupture tests at 750° C., which was determined in the earlier work.[4] This elongation,* which is henceforth denoted as D, should be qualitatively related to the ductility of the alloy in the warm-working process, and—for want of more suitable data—it is used as a criterion of the material's ductility.

In the results that follow an attempt has been made to show the effect of some systematic composition

* Creep strength is here defined as the stress required to produce a specific strain in a given time.

* The $L\sqrt{A}$ of the small creep specimens used is 6·3.

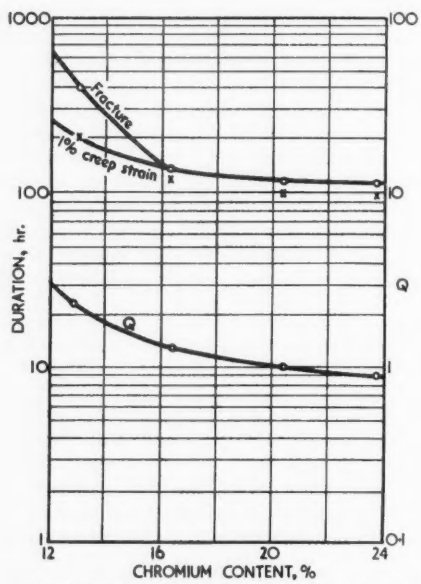

Fig. 1—Effect of the chromium content of alloys with 3% W, 3% Mo, 3% Nb, 0·5% C, and a 20% Ni, 20% Co base, on the results of creep tests at 12 tons/sq. in. at 750° C. on warm-worked material

changes on the rupture strength of the warm-worked alloys. In only a few convenient cases have the values of Q been shown graphically. To facilitate a comparison with the equivalent solution-treated alloys, the value of Q for some of the more interesting alloys is mentioned in the text. Only where the value of Q is greater than 2 is the result considered to be sufficiently significant to show that the alloy is suitable for warm-working. A more detailed comparison of solution-treated and warm-worked alloys has been given in the earlier paper.[4] As the elongation at fracture of the warm-worked material is very dependent on the warm-working conditions and shows little systematic variation with composition, it is not shown in the graphical results. The values obtained are between 1% and 3% in most instances.

EFFECT OF THE BASE COMPOSITION

The effect of the chromium content of alloys with 3% W, 3% Mo, 3% Nb, 0·5% C, 20% Ni, and 20% Co is shown in Fig. 1. These alloys do not warm-work well, but the 13% alloy is the most suitable. It is noteworthy that the value of D fell continuously from 12% to 6% as the chromium content was raised.

The effect of the Ni : Co : Fe ratio of the base of similar alloys with 3% W, 3% Mo, 3% Nb, 0·5% C, and 19% Cr is shown in Fig. 2. As the Ni % + Co % + Fe % of these alloys totals approximately 70%, the results may be shown on a Ni–Co–Fe 'ternary' graph. Values of the rupture time are plotted as a function of the composition of the base, and 'iso-rupture time' lines are drawn. It will be seen that the superiority of the high-cobalt alloys is marked.

The only alloys having Q values significantly greater than 2 are the 30% and 50% Co alloys with no nickel, which have Q values of 8 and 4 respectively. All the 'binary' Co–Fe alloys are extremely difficult to machine; for example, drilling can be carried out only when using tungsten carbide. Values of D for these alloys are less than 5%, except for nickel-rich alloys, where values of approximately 10% are found.

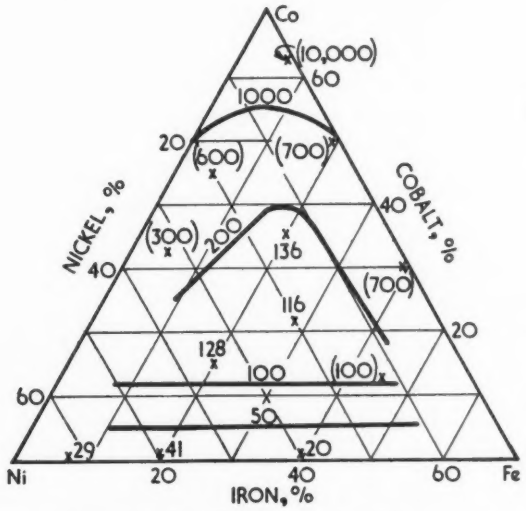

Fig. 2—Effect of the Ni: Co: Fe ratio of the base, of alloys with 70% of Ni + Co + Fe, 3% W, 3% Mo, 3% Nb, 0·5% C, and 20% Cr, on the fracture time (hr.) at 12 tons/sq. in. at 750° C. of warm-worked material. The figures within brackets are estimated from tests at higher stresses

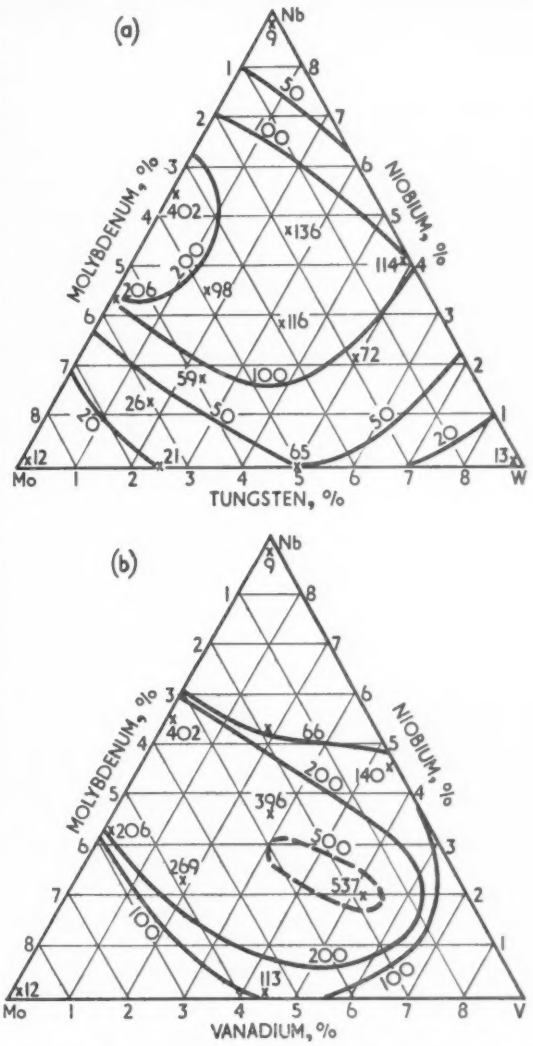

Fig. 3—Effect on the fracture time (hr.), at 12 tons/sq. in. at 750° C. of warm-worked material, of (*a*) the W:Mo:Nb ratio of alloys with 9% of W + Mo + Nb, 0·5% C, and a 20% Ni, 20% Co, 20% Cr base, and (*b*) the V:Mo:Nb ratio of alloys with 9% of V + Mo + Nb, 0·5% C, and a 20% Ni, 20% Co, 20% Cr base

EFFECT OF CARBON AND CARBIDE-FORMING ELEMENTS

The effect of varying the W:Mo:Nb ratio in alloys containing 9% of these elements, 0·5% C, and having a 20% Ni, 20% Co, 20% Cr base, is shown in Fig. 3*a*. As the W% + Mo% + Nb% of these alloys is constant at 9%, a 'ternary' graph of these elements has been drawn in a similar manner to the graph in Fig. 2. Values of Q for these alloys are generally

Table II

EFFECT OF MISCELLANEOUS TI–MO–NB AND AL–MO–NB ADDITIONS TO 0·5% C ALLOYS, WITH A 20% NI, 20% CO, 20% CR BASE, ON THE RESULTS OF CREEP TESTS

Creep tests at 12 tons/sq. in. at 750° C. on warm-worked material

Alloy Composition, %					Time, hr., to:		Elongation, %	Q	D, %
Quality	Ti, %	Al, %	Mo, %	Nb, %	1% Creep Strain	Fracture			
L243 EF660	0·7	...	3·2	3·6	700	845	3·0	6·0	12·0
L244 EF661	0·7	...	4·9	1·8	270	473	5·0	2·9	13·0
L246	1·8	...	2·8	2·4	30	77	10·0	1·4	15·0
L247	3·9	...	4·8	...	55	70	3·0	1·2	6·0
L243 EF704	1·1	...	4·0	3·5	115	169	3·0	2·3	18·0
L249	...	0·7	3·5	3·9	740	750	2·0	5·8	11·0
L250	...	2·6	4·9	2·1	143	196	2·0	1·4	20·0
L251	...	2·0	1·7	4·4	225	241	2·0	4·5	23·0
L252	...	2·7	2·8	4·6	47	95	3·0	1·1	5·0
L254	...	3·7	...	4·6	130	136	2·0	2·1	9·0

considerably less than 2, but the two Mo–Nb alloys have values of approx. 2·5. The *D* values of these alloys increase from 3% at the Mo corner to values of over 10% on the W–Nb line.

Results for a similar series of alloys, but with V replacing W, are shown in Fig. 3*b*. The optimum alloys of this series are somewhat better than those of the W–Mo–Nb series, and the 'ternary' field of alloys, having a fracture time of over 200 hr., is considerably larger. The 'peak' alloy of this system has also the highest *Q* value—approx. 3. A large part of the 'ternary' area has *D* values greater than 20%.

Table II shows the effect of miscellaneous additions of Ti–Mo–Nb and Al–Mo–Nb to 0·5% C, 20% Ni, 20% Co, 20% Cr alloys. Alloys containing approx. 3·5% Mo, 3·5% Nb, and 0·7% of either Ti or Al, will be seen to warm-work very successfully.

The effect of the carbon content of 3% V, 3% Mo, 3% Nb alloys with a 20% Ni, 20% Co, 20% Cr base is shown in Fig. 4. It is interesting that only the alloys with less than 0·6% of carbon have been improved by warm-working and that, although the absolute strength of the 0·05% C alloys is so low, their *Q* value is 180. The values of *D* for these alloys tend to rise with increasing carbon content, and the creep and rupture properties pass through a pronounced maximum.

The effect of the simultaneous addition of carbon and the carbide-forming elements V, Mo, and Nb to a cobalt-based 19% Cr alloy with a Ni:Co:Fe ratio of 15 : 40 : 15 is illustrated in Figs. 5*a* and *b*. The V: Mo: Nb ratio of all the alloys was 1: 1: 1. The peak alloy, for which *Q* is 6, has very useful properties at both 750° and 800° C. The importance of a careful balance between carbon and the carbide-forming elements is evident.

Whereas all the low-carbon alloys (0·05–0·10%) were improved by warm-working, only those alloys with more than 6% and 8% of carbide-formers were improved in the medium-carbon (0·25–0·33%) and high-carbon (0·44–0·51%) series respectively. This would be expected, as an increase in the ratio of carbide-forming elements to carbon is known to improve the ductility (*D*), possibly by suppressing the formation of embrittling chromium-rich carbides.

The optimum amount of the carbide-forming elements (V + Mo + Nb) for solution-treated alloys with 0·3% of carbon was found to be 6½%. It will be seen from Fig. 5 that the optimum amount for warm-worked materials is about 9%. Such an alloy is too ductile in the solution-treated condition, but the excess ductility is eliminated and, indeed, needed in the warm-working process.

The effect of varying the V:Mo:Nb ratio of alloys with 6% of these elements, 0·3% of carbon and a 16% Ni, 42% Co, 19% Cr base, is shown in Fig. 6. None

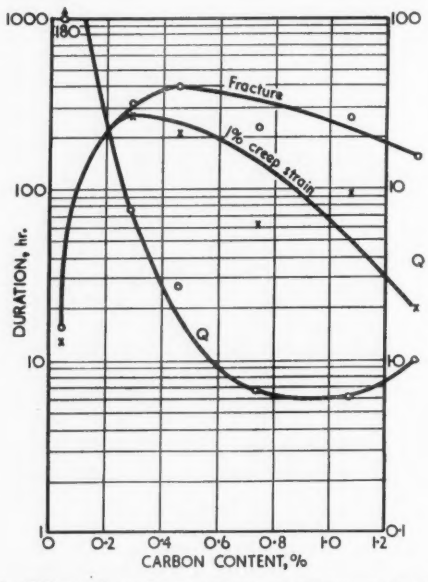

Fig. 4—Effect of carbon content of alloys with 3% V, 3% Mo, 3% Nb, and a 20% Ni, 20% Co, 20% Cr base, on the results of creep tests at 12 tons/sq. in. at 750° C. on warm-worked material

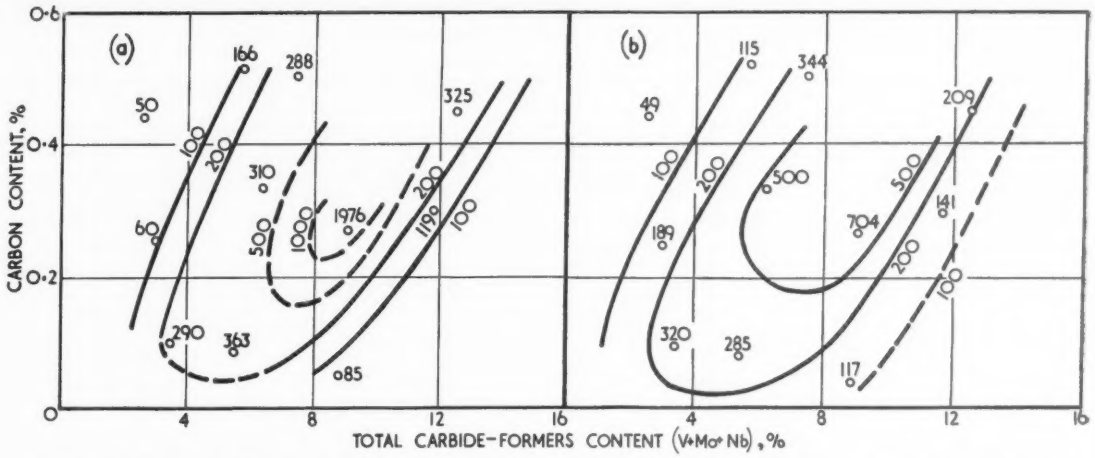

Fig. 5—Effect of simultaneous additions of carbon and the carbide-forming elements V, Mo, and Nb, to a 19% Cr alloy with a base having a Ni:Co:Fe ratio of 15:40:15, on the fracture time (hr.) at (*a*) 14 tons/sq. in. at 750° C. and (*b*) 10 tons/sq. in. at 800° C. of warm-worked material

of these alloys has Q values significantly greater than 2, as would be anticipated from Fig. 5.

FURTHER TESTS WITH MODIFIED HEAT-TREATMENTS

It is now known that the solution treatment used for the preceding investigations is not the most effective for this type of alloy. A considerable improvement in high-temperature strength results when the soaking time at the solution temperature of 1280° C. is extended to 10 min. and the material is oil-quenched. Table III gives the results of creep tests cn some of the more outstanding alloys of this work, solution-treated in such a way and warm-worked at 700° C. by about 5%.

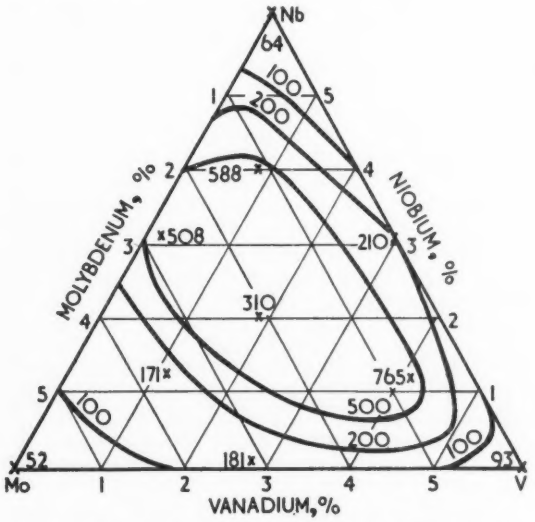

Fig. 6—Effect of the V:Mo:Nb ratio of alloys with 6% of V + Mo + Nb, 0·3% C, and a 16% Ni, 42% Co, 19% Cr base, on the fracture time (hr.) at 14 tons/sq. in. at 750° C. of warm-worked material

Included in these alloys is a nickel-free high-cobalt modification of the optimum alloy of Fig. 5. This alloy, which contains 0·36% C and 3% V, 3% Mo, 3% Nb, has very similar rupture properties to the other 64% Co alloy containing 0·5% C and 3% W, 3% Mo, 3% Nb.

As these tests were carried out at higher stresses to minimize the amount of testing, a direct comparison with the previous results is not possible. Figure 7, however, shows graphically the extent of the improvement achieved; it should be emphasized that the carbon and carbide-forming elements vary in the alloys shown in this diagram.

GENERAL CONCLUSIONS

Consideration of the above test results leads to the following conclusions.

For the type of alloy under consideration, *i.e.*, an austenitic alloy strengthened by precipitation of miscellaneous carbides, a cobalt-rich matrix is the

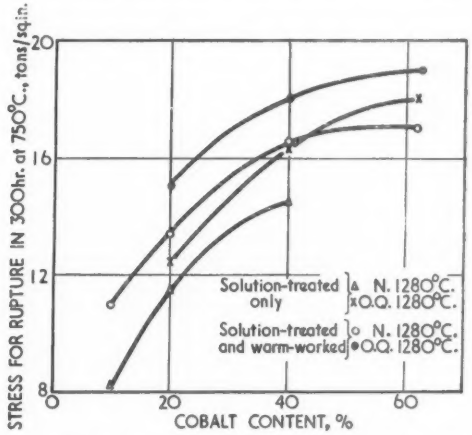

Fig. 7—Effect of cobalt and heat-treatment on the properties of warm-worked material

Table III

RESULTS OF CREEP TESTS ON A SELECTION OF OUTSTANDING ALLOYS

Improved solution-treatment: Oil-quenched from 1280° C. after 10-min. soak

Base Composition (+ 19–20% Cr), wt.-%	Carbon, wt.-%	Carbide-Forming Elements, etc., wt.-%	Stress, tons/sq. in.	Temperature, °C.	Time, hr., to:		Elongation at Fracture, %	Alloy Also Shown as Under
					1% Creep Strain	Fracture		
30 Co, 40 Fe	0·5	3 W, 3 Mo, 3 Nb	16	750	150	167	2·3	Fig. 2
			12	800	86	87	2·5	
50 Co, 30 Fe	0·5	3 W, 3 Mo, 3 Nb	16	750	660	662	2·5	Fig. 2
			12	800	338	339	1·5	
64 Co, 6 Fe	0·5	3 W, 3 Mo, 3 Nb	18	750	551	552	1·6	Fig. 2
			14	800	186	186	1·0	
20 Ni, 20 Co, 30 Fe	0·5	5·5 Nb, 3·5 Mo	16	750	12	13	1·8	Fig. 3
			12	800	24	79	9·1	
20 Ni, 20 Co, 30 Fe	0·5	5 V, 2 Mo, 2 Nb	16	750	110	218	11·7	Fig. 3
			12	800	20	40	15·4	
20 Ni, 20 Co, 30 Fe	0·5	0·7 Ti, 3·2 Mo, 3·6 Nb	16	750	68	69	3·3	Table II
			12	800	65	80	4·3	
20 Ni, 20 Co, 30 Fe	0·5	0·7 Al, 3·5 Mo, 3·9 Nb	16	750	100	125	2·3	Table II
			12	800	60	93	4·5	
20 Ni, 20 Co, 30 Fe	0·27	3 V, 3 Mo, 3 Nb	16	750	90	97	3·1	Fig. 4
15 Ni, 40 Co, 15 Fe	0·33	3 V, 3 Mo, 3 Nb	18	750	200	324	9·1	Fig. 5*
			14	800	100	311	17·3	
64 Co, 6 Fe	0·36	3 V, 3 Mo, 3 Nb	20	750	100	120	4	—†
			14	800	90	234	9	

* Remelt of optimum alloy of Fig. 5, warm-stamped 5% at 650° C.
† Nickel-free, high-cobalt modification of the optimum alloy of Fig. 5

most suitable. When carbide formers are progressively added to such an alloy of given carbon content, or when the carbon content is progressively increased with given carbide-forming elements present, the high-temperature strength of the warm-worked material passes through a maximum. This indicates the necessity for the careful balancing of carbon and carbide-formers for optimum properties. The ratio of carbon to carbide-formers for optimum strength is somewhat less for warm-worked material than for solution-treated material.

In general, the optimum alloy for warm-working is not the most ideal for use in the solution-treated condition. As with the solution-treated material, there exists a ' complexity ' effect whereby the high-temperature strength properties of an alloy can be improved by increasing the number of carbide-formers present.

The solution treatment of the alloy should be a somewhat lengthy soak (10–15 min.) at the solidus of the alloy, followed by quenching in oil or water.

No consideration of the optimum warm-working conditions is made here, but this is dealt with in the case of *G18B* in another paper.[3]

Alloys that have a low ductility in the solution-treated condition are not suited for warm-working. If the ductility is high, the alloy may or may not be suitable. The carbide-forming elements Nb, V, and Ti impart ductility to alloys of the type investigated, because, owing to their strong carbide-forming tendency, they inhibit the formation of embrittling chromium-rich carbides. Consequently, some of these elements are present in the better alloys.

The general effect of some of these variables is shown in Fig. 7, which compares solution-treated and warm-worked materials. The properties shown are an estimate of the rupture strength at 750° C. of correctly proportioned alloys. In the case of the warm-worked alloys, the properties are those likely to be obtained by stamping between flat dies. The superiority of oil-quenching over normalizing is indicated for both solution-treated and warm-worked materials. It will be seen that, although warm-working is very effective in improving the rupture strength of the alloys with a base containing small amounts of Co, the percentage improvement in the higher-cobalt alloys is less marked.

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Permeability Tests on Blast-Furnace Raw Materials

By E. W. Nixon, B.Met., A.I.M., and F. R. Maw, B.Met., L.I.M.

SYNOPSIS

Test apparatus used to study the permeability of blast-furnace burden materials is described. Possibilities of its use for practical, as well as fundamental, research are given, together with examples of test results.

Although no investigation of fundamental flow data has yet been completed, the series of tests carried out so far indicate that the apparatus has distinct possibilities for solving empirical burdening problems.

Examples are: (i) the importance of size distribution on coke permeability, together with the related effects of breakdown due to shatter; and (ii) the important effect of small size fractions on burden permeability. 782

ONE of the major factors controlling the performance of a blast-furnace is the permeability of the materials in the stack. There is little published information on this subject that can be applied directly to the solution of blast-furnace problems, such as the relative permeabilities of the constituents of the burdens (*e.g.*, sinter, coke, ironstone) and of different mixtures of these materials.

Furnas[1] carried out extensive preliminary work on this subject, but concentrated mainly on formulating empirical laws governing the flow of gases through beds of materials of single size grades only; he did not refer to mixtures of large size grades.

Lowry[2] has used a permeability apparatus of a similar size for testing cokes only, as part of a complete set of tests involving screen analysis, shatter test, drum test, moisture determination, and permeability. As far as is known, he has not carried out any tests on other materials. His equipment is the basis of the design of the apparatus used in these tests.

When deciding on the size of the apparatus, consideration was given to the wall effect of the cylinder to avoid errors when comparing fine materials with coarser materials up to 3–4 in. in screen size. Mott[3] contends that when d/D (d = dia. of particles; D = dia. of cylinder) is 0·10 or less, the wall effect is negligible when using beds of spheres; for beds of large irregular particles, although there is no evidence that the wall effect is negligible below a ratio of $d/D = 0{\cdot}10$, it is known that bridging occurs for ratios larger than 0·167. For materials with a general maximum size of 3–4 in., the chosen cylinder diameter of 36 in. gives a ratio of about 0·1.

The height of the apparatus was limited by the headroom on the site and by the quantities of materials involved.

Experimental work using this apparatus can be on either fundamental or practical aspects. A programme of work for evolving fundamental relationships between shape factor, specific surface, proportions of various size grades, and bulk density of the various materials charged into the blast-furnace has been started. However, owing to the value of empirical tests in giving a guide to the combined effect of alterations in physical characteristics and proportions of burden materials, the apparatus has been used mainly to give empirical comparisons.

Several series of tests were carried out which guided and assisted furnace operators during the difficult time when the operation of enlarged ore-preparation plant was leading to the use of burdens that were entirely different physically; the first use of 100% sinter burdens was accelerated by these test results.

PERMEABILITY APPARATUS

The apparatus consists of a mild-steel cylinder, 7 ft. high by 3 ft. internal dia., of all-welded construction (*see* Fig. 1). The cylinder is connected to the 3 ft. 6 in. dia. cold-blast main of one of the large blast-furnaces at Appleby-Frodingham *via* a 6-in. dia. pipe. The bed of material to be tested rests on a distributor plate 1 ft. from the bottom of the cylinder; this plate has 256 ½-in. dia. holes per sq. ft., giving an area of openings of about 35%.

The cylinder is provided with a discharge door for easy removal of materials. A cleaning door is provided for cleaning out the plenum chamber. Both doors have machined faces and seatings, and are fitted with asbestos seals to give an airtight joint.

The air enters the cylinder through a 12-in. dia. inlet, the supply being controlled by two 6-in. valves, one immediately after the tapping in the cold-blast main and the other about 3 ft. from the inlet.

The pressure at the bottom of the bed is measured by means of a six-hole piezometer ring, 2¼ in. above the distributor plate, and connected to a water **U**-gauge. Static pressure is measured with a Bourdon gauge just before the orifice plate.

The gas flow is measured by a 4·518-in. dia. orifice connected to a differential mercury gauge. Rates of flow from 800 to 4500 cu. ft./min. are available at a delivery pressure of 15–18 lb./sq. in. The temperature of the cold blast is measured with a 0–100° C. mercury

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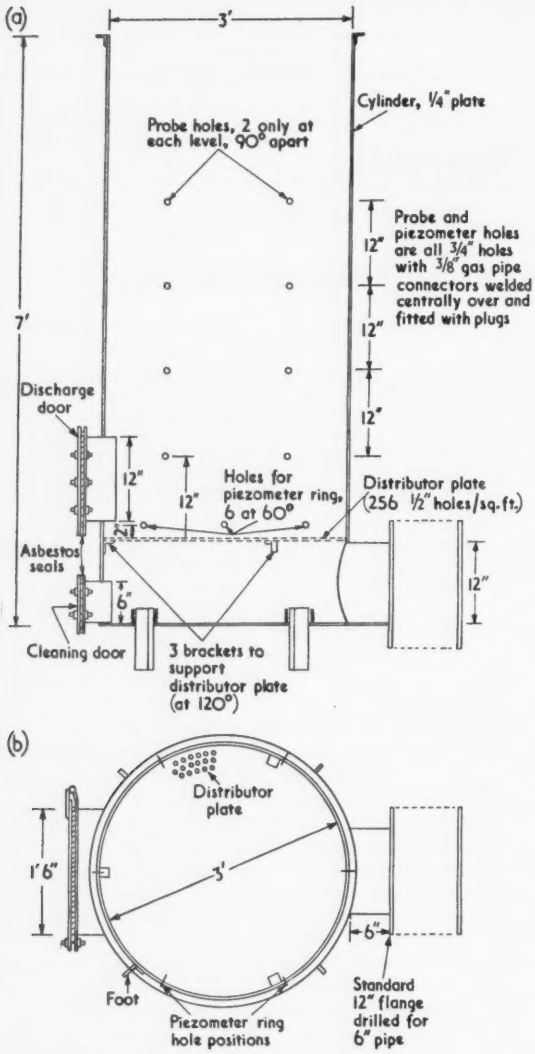

Fig. 1—Section and plan of test cylinder

thermometer in a socket immediately before the orifice plate.

Materials are loaded into the cylinder by a charging hopper, which is hoisted with a chain and pulley block running along an overhead rail. The hopper has bottom discharge doors which can be released from the top when the hopper is resting on the distributor plate, allowing it to be drawn upwards, and leaving the materials in the cylinder. After testing, materials are raked out from the discharge door, using a small detachable chute if necessary.

The capacity of the cylinder is about 35 cu. ft., so that the weight of coke required for a test is about 1000 lb. and that of ironstone 2500–3000 lb.

MATERIALS

The permeability apparatus is situated on ground-level under the end of the stove platform of the blast-furnaces. To make the tests represent as closely as possible the conditions existing at stockline level, materials are usually taken from the furnace bunkers. The sample is drawn from the bunkers into the scale car, which then runs out from under the bunkers and drops the material between the rails. The sample is then transported by dumper or lorry to the testing site and stocked under cover of the platform. To avoid undue variability, enough of each material must be obtained to complete the whole series of tests from the single bulk sample, and this limits the number of tests per series to the amount that can be conveniently stocked—about 8 or 9. Any further screening or pre-treatment before testing is done on the site. When coke is required as part of the test mixture, it is collected by discharging the furnace coke weigh hopper, which normally fills the skip, on to the skip-pit floor, where it is shovelled into sacks and transported to the testing site.

Whenever possible, all materials are subjected to screen analysis, bulk density (in a 2-cu. ft. box), and shatter tests (in the case of coke). The effect of quite small changes in one component can be detected, provided that sufficient care is taken to ensure uniformity of materials over a series of tests. Special precautions are taken to ensure that the materials do not get wet, by stocking under the stove platform and sheeting down, for moisture has a marked effect on flow rates and pressure drop.

Charging the Cylinder

All materials are weighed before charging. Generally, three hopper loads are required for a charge, and the materials for each hopper are thoroughly mixed on the ground before charging. The loaded hopper is hoisted with the chain block, lowered into the cylinder, and withdrawn after releasing the doors. When the complete charge has been loaded, the top is levelled with a rake.

Method of Testing

The bed depth is measured with a graduated wooden set-square at several positions at stockline level and the mean depth is recorded.

The valve on the cold-blast main is opened fully and the rate of flow is then controlled by the second valve after the orifice plate. This is opened a little and all piezometer-ring joints and doors are checked

Table I

SCREEN ANALYSES OF COKES USED

Coke Size	Analysis Before Shattering, %		Analysis After Shattering, %	
	Coke A	Coke E	Coke A	Coke E
+ 4 in.	9·6	6·1	3·7	1·6
4–3 in.	26·9	15·3	10·5	5·9
3–2 in.	38·8	42·4	39·5	33·5
2–1 in.	20·9	27·6	35·2	43·0
1–½ in.	2·2	4·4	7·0	11·7
− ½ in.	1·6	4·2	4·1	4·3

Table II

SHATTER TEST ON + 2-IN. MATERIAL AS-RECEIVED

Coke	Shatter Test			
	+ 2 in.	+ 1½ in.	+ 1 in.	+ ½ in.
A	69·2	84·4	93·0	97·5
E	51·0	72·4	86·9	96·2

for leakages. The run is then begun. Readings of the pressure at the bottom of the bed are taken at intervals of 0·5 in. on the mercury differential gauge until the maximum reading is obtained on either the 36-in. water gauge connected to the piezometer ring or the 12-in. mercury differential gauge. A further set of readings is taken again at intervals of 0·5 in. of Hg as the rate of flow is decreased to zero. The cold-blast temperature is measured with a 0–100° C. mercury thermometer immediately before the orifice plate.

Method of Reporting Results

The rates of flow are obtained from the orifice calibration graph and are corrected by calculating a correction factor which gives the rate of flow at N.T.P. at gauge pressures and temperatures other than those for which the orifice was calibrated. The pressure drop is then plotted against the rate of flow at N.T.P. and a curve is drawn through the points. Normally, for this type of plant testing, no correction is made for barometric pressure, since the inaccuracy of a Bourdon-gauge reading swamps any errors introduced by not correcting for barometric pressure.

EXAMPLES OF TESTS CARRIED OUT

Example 1—Tests on Coke As-Received

The apparatus can distinguish easily between high- and low-permeability cokes, but it is not suitable for distinguishing cokes very similar in size distribution; a simple screen analysis may be just as useful.

Little further information can be gained by using the test on cokes in the as-received condition. The best line of investigation seems to be to study the effect on flow characteristics of the different size grades and angularities of cokes, and their interactions.

Example 2—Effect of Shattering the Coke on the Flow Characteristics

Figure 2 illustrates the effect of subjecting two cokes made from South Yorkshire slacks to breakdown equivalent to the standard shatter test; one coke has a good shatter index and the other a poor index (*see* Tables I and II). The deterioration of flow characteristics on the weaker coke is much greater than on the stronger coke, as is clearly indicated.

Example 3—Synthetic Sinter Mixtures

The flow curves for this series of seven tests are given in Fig. 3. Details of the tests are as follows. The basic burden mixture used in all tests was:

Frodingham reclaimed bedded	35%
Dried Northants rubble	23%
Sinter	42%

Three grades of sinter were used:

A + 1 in.; *B* 1–¼ in.; *C* − ¼ in.

The basic sinter mixture was:

Grade *A* 20%; Grade *B* 50%; Grade *C* 30%

The following combinations of grades were used, keeping the same basic burden mixture in each test:

ABC, *B*, *BC*, *AB*, *AC*, *A*, *C*.

The most striking feature in this series was the very large increase in pressure drop caused by using all − ¼-in. sinter in the mixture; the resistance to flow of the bed was increased so much that on

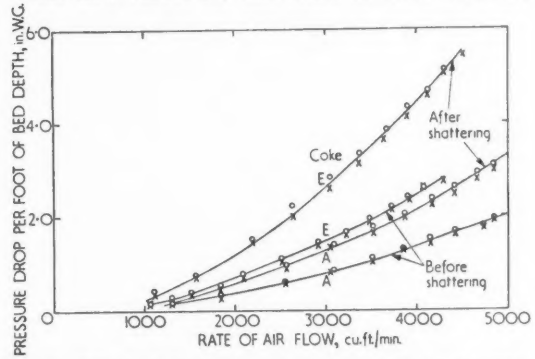

Fig. 2—Effect of shattering on the flow of air through a bed of coke

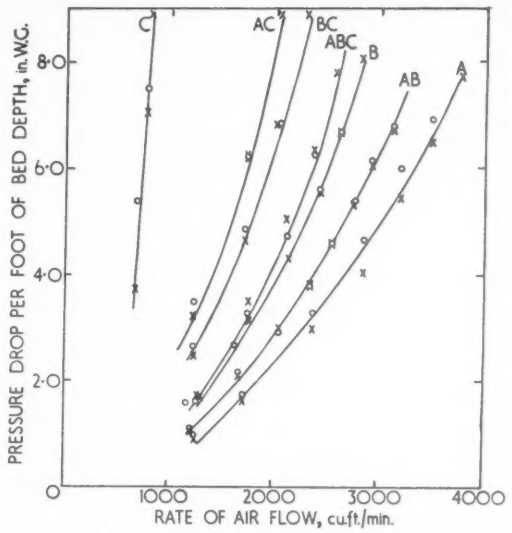

Fig. 3—Synthetic sinter mixtures

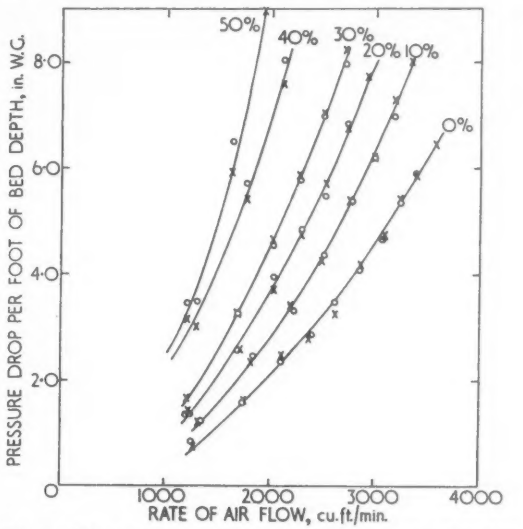

Fig. 4—Effect of the percentage of − ¼-in. size fraction in sinter

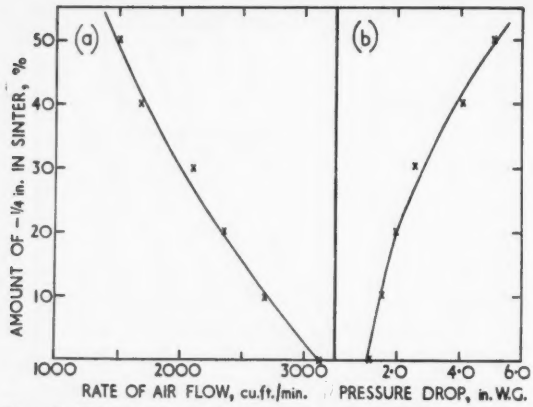

Fig. 5—Effect of − ¼-in. sinter on synthetic sinter mixtures: (*a*) Air flow at a pressure drop of 5 in. W.G.; and (*b*) pressure at air flow of 1500 cu. ft./min.

increasing the rate of flow from 680 to 803 cu. ft./min. the pressure drop increased by 5·1 in. W.G. per foot of bed depth.

The elimination of both the middle size and the large size proved detrimental to the flow of air, but the elimination of the smallest size and the use of the middle and large sizes alone proved beneficial.

The use of a mixture of the middle and large sizes was better than the middle size alone, and the use of the large size alone gave the best rate of flow of the series.

In practice, as it would be impossible to use only one size grade in sinter, the best plan is to reduce or eliminate the smaller size grades.

Example 4—Effect of Percentage of − ¼-in. Grade in the Sinter on the Flow through a Bed of Burden Materials

The burden mixture used in all the tests was the same as in the previous example.

Six tests, increasing the percentage of − ¼-in. grade in the sinter from 0 to 50 in increments of 10%, were carried out. The basic sinter mixture was the same as in Example 3. The flow curves of these six tests are given in Fig. 4. This series demonstrates the sensitivity of the test, as the difference between each 10% increment of − ¼-in. material amounted to only 4% of the total charged weight.

The effect of the percentage of − ¼-in. material is further illustrated in Fig. 5. Figure 5*a* shows this effect on the rate of flow of air through the bed at a pressure drop of 5 in. W.G. per foot of bed depth, and Fig. 5*b* shows the effect on the pressure drop through the bed at a rate of flow of 1500 cu. ft./min. (approx. equivalent flow in the 3-ft. dia. apparatus to that obtained on a 20-ft. dia. stockline furnace).

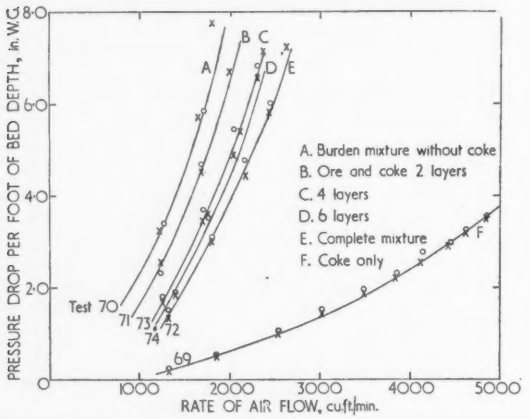

Fig. 6—Effect of layer charging and of coke in the charge

Example 5—Effect of Coke and Layer Charging on the Flow of Air through a Bed of Burden Materials

Figure 6 shows the curves obtained in this series of tests, which were as follows:

Test 69 Using 100% Appleby-Frodingham coke
Test 70 Using the following burden mixture:
Frodingham reclaimed bedded 30%
Dried Northants rubble 25%
Sinter 45%
Test 71 Using two layers of material—one of coke and one of burden materials (ore/coke ratio 2·8/1)
Test 72 Using complete mixture of coke and burden materials (ore/coke ratio 2·8/1)
Test 73 Using four layers of material—two of coke and two of burden materials (ore/coke ratio 2·8/1)
Test 74 Using six layers of material—three of coke and three of burden materials (ore/coke ratio 2·8/1)

The very high permeability of coke as compared with the other materials is well illustrated in this series.

An intimate mixture of all the materials used gives higher permeability than do separate layers of burden mixture and coke. For thicker layers the overall permeability is less, but as the number of layers increases and the thickness decreases, more intermixing occurs at the junction of the layers, and the permeability approaches that of the intimate mixture.

Example 6—Effect of Adding a Small Amount of Relatively Large Material to a Bed Composed of Sinter and Coke Only

Curves obtained in this series are given in Fig. 7. The addition of 5% of Frodingham reclaimed bedded

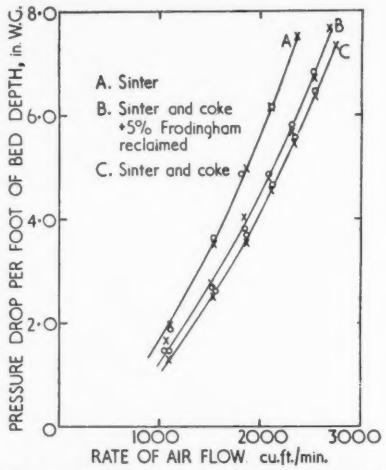
PRESSURE DROP PER FOOT OF BED DEPTH, in. W.G.
RATE OF AIR FLOW cu.ft./min.
A. Sinter
B. Sinter and coke +5% Frodingham reclaimed
C. Sinter and coke

Fig. 7—Effect of adding a small amount of relatively large material to a bed composed of sinter and coke only

ironstone to a bed consisting of only sinter and coke increased the resistance of the bed to the flow of air, the pressure drop increasing by 0·32 in. W.G. per foot of bed depth at a rate of flow of 1500 cu. ft./min. The following screen analyses show that the Frodingham reclaimed bedded ore was of much larger size than the sinter:

Screen Analysis	Coke, %	Sinter, %	Frodingham Reclaimed Ore, %
+4 in.	0·8	1·5	9·5
4–3 in.	9·4	4·2	16·5
3–2 in.	41·1	2·2	24·8
2–1 in.	40·0	13·8	34·8
1–¾ in.	5·3	11·4	6·4
¾–½ in.		18·3	2·8
½–¼ in.	3·4	28·3	1·5
−¼ in.		20·3	3·7

Acknowledgments

The work described was carried out in the Ironworks Section of the Metallurgical Department of the Appleby-Frodingham Steel Company, and the authors are indebted to Mr. G. D. Elliot, Works Manager (Iron), and to their departmental head, Dr. L. Reeve, for their encouragement and guidance in this investigation. They also wish to thank the management of the Company for permission to publish this paper.

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2. H. H. Lowry: Private communication.
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Determination of Copper in Iron and Steel

By the Methods of Analysis Committee

SYNOPSIS

Examination of existing British Standard methods for the determination of copper in permanent-magnet and low-alloy steels has shown that these procedures, as such, cannot be applied to many highly alloyed steels. Modification of the method of dissolving the sample, and the introduction of an alternative reagent, potassium thiocyanate, to precipitate the copper, has enabled a single method to be proposed. Experimental evidence shows that improved results can be obtained by the revised procedure, which provides for the analysis of all classes of steel. The only weakness of the method is the loss of accuracy, owing to slight solubility of cuprous thiocyanate, which becomes significant only where the copper content is under 0·1%. In such cases it is recommended that a modification using sodium-thiosulphate precipitation should replace potassium thiocyanate. 774

Two methods for the determination of copper are at present in existence as British Standards;[1, 2] they cover a range of compositions in the permanent-magnet and low-alloy class of steels. As these two procedures are now under review, the present investigation has aimed at their extension and, if necessary, modification, in such a way as to provide a method that could be applied to *all* classes of steel. This work has been carried out by the Highly Alloyed Steels and Ferro-Alloys Analysis Sub-Committee, the constitution of which is given in Appendix II.

DETAILS OF INVESTIGATION

To facilitate this work, a Study Group of three members was formed. The conclusions of the group were later passed to the Sub-Committee for comment and trial.

The fundamental differences between the two procedures under review lie in the reagents used to dissolve the sample initially and, at a later stage, to precipitate the copper. The precipitating reagent recommended in B.S.1121, Part 5, is hydrogen sulphide, and that recommended in Part 14 is sodium thiosulphate.

In the analysis of the highly alloyed steels, as distinct from low-alloy steels, it is often necessary to use an oxidizing agent in the early stages of the method. This preliminary treatment can be followed by reduction with sulphurous acid and hydrolysis, thereby enabling elements such as titanium, tantalum, niobium, tungsten, and silicon to be quantitatively removed by filtration.

A series of samples (Table I) was first examined to investigate the extent to which this preliminary treatment could be applied, for it is known that small amounts of tungsten, present in complex steels, are not completely hydrolysed by sulphurous acid, and this might have caused interference at a later stage. Also, the extent to which copper might be associated with the discarded hydrolysis product was unknown.

Using a 5-g. sample, solution was obtained with hydrochloric acid, followed by nitric-acid oxidation. In some cases a mixture of these acids was used as the solvent. After evaporation and extraction with hydrochloric acid, the solution was reduced with 100 ml. of sulphurous acid. After filtration the insoluble residue and filtrate were examined separately for copper.

In one series of tests sodium thiosulphate was used to precipitate the copper, in another hydrogen sulphide was used, and in both cases the determinations were completed volumetrically with standard sodium-thiosulphate solution as recommended in B.S.1121.[2] The results reported by the three operators using the thiosulphate method were:

Cu 1	0·21–0·22% of copper
MGS 63	0·17–0·18% ,, ,,
MGS 151	0·095–0·10% ,, ,,
MGS 166	0·18–0·20% ,, ,,

Copper in the insoluble residue averaged 0·001% in each test.

Paper MG/D/48/53 of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 8th April, 1953.

Molybdenum does not interfere. The only weakness of the method is the slight solubility of cuprous thiocyanate. This becomes significant when the copper content is under 0·1%, and precipitation with sodium thiosulphate in place of potassium thiocyanate provides more accurate results in this range.

References

1. " Copper in Permanent Magnet Alloys ": British Standard 1121, Part 5, 1948.
2. " Copper in Carbon and Low-Alloy Steels ": British Standard 1121, Part 14, 1949.

APPENDIX I

Recommended Method for Copper Determination

Solutions Required

Sulphurous acid
Ammonium hydroxide (1:1)
Sulphuric acid (1:99)
Sodium sulphite (25%)
Sulphuric acid wash—1 litre of H_2SO_4 (1:99), 10 ml. of sodium-sulphite solution (25%), and 5 ml. of potassium thiocyanate solution (20%).
Nitric acid (1:1)
Sulphuric acid (1:1)
Potassium iodide (60%)
Potassium thiocyanate (20%)
Starch (1%)
Standard sodium thiosulphate. Dissolve 4 g. of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) in water containing 0·1 g. of Na_2CO_3 and dilute to 1 litre. 1 ml. is approximately equivalent to 1 mg. of copper.
Standard copper solution. Dissolve 1 g. of pure copper in 10 ml. of water and 5 ml. of nitric acid (sp. gr. 1·42), boil, cool, and dilute to 1 litre.

Procedure

Dissolve 5 g. of sample (*see* Note 1) in 50 ml. of hydrochloric acid (sp. gr. 1·16), oxidize with nitric acid (sp. gr. 1·42), and evaporate to dryness. Add 30 ml. of hydrochloric acid (sp. gr. 1·16) and evaporate to 20 ml. Add 100 ml. of hot water, 100 ml. of sulphurous acid, boil, and filter through a paper-pulp pad (Note 2). Wash with sulphuric acid (1:99) and collect the filtrate and washings in a 600-ml. squat beaker. Warm to 70° C. (Note 3), add ammonium hydroxide (1:1) until a faint permanent precipitate appears, redissolve this precipitate with sulphuric acid (1:1) and add 5 ml. excess. Add 40 ml. of sodium-sulphite solution (25%), 10 ml. of potassium-thiocyanate solution (20%), and boil for 2 min.

Cool the solution to room temperature (Note 4), filter through a paper-pulp pad, and wash with sulphuric-acid wash. Dissolve the precipitate through the pad into the original beaker with 40 ml. of nitric acid (1:1) (Note 5) and wash with hot water.

Add 3 ml. of sulphuric acid (1 : 1), evaporate to fumes, cool, and add 10 ml. of water. Add 0·5 g. of sodium fluoride, neutralize with ammonium hydroxide (1:1), cool, acidify with glacial acetic acid, add 1 ml. in excess, and again cool. Add 5 ml. of potassium iodide (60%) and titrate with sodium-thiosulphate solution until the brown colour is almost discharged. Add 2 ml. of starch solution, 10 ml. of potassium thiocyanate solution (20%), and titrate until the blue colour is discharged.

Standardize the sodium-thiosulphate solution against 25 ml. aliquots of the standard copper solution treated as in the last paragraph.

Notes

(1) For copper contents greater than 0·25% use a 2-g. sample, for those greater than 0·5% use a 1-g. sample, and for those greater than 1·0% use a 0·5-g. sample; where necessary use a suitable aliquot of the solution.

Replicate results on a 5-g. sample should be within ± 0·005% of copper.

(2) If tungsten, tantalum, or niobium are present, allow to stand for at least 1 hr. before filtering.

(3) When the copper content is below 0·1%, greater accuracy can be obtained as follows:

Boil and add cautiously 15 g. of sodium thiosulphate ($Na_2S_2O_3.5H_2O$). Boil for 10 min., filter through a Whatman No. 540 filter paper, and wash well with water containing a little hydrogen sulphide. Dry the paper and precipitate in a silica crucible and burn off carbonaceous matter below 550° C. Cool, dissolve in 5 ml. of nitric acid (sp. gr. 1·42), and transfer to a small beaker. Add 3 ml. of sulphuric acid (1:1), and proceed as in the third paragraph of ' Procedure.'

(4) When the copper content is below 0·1%, improved accuracy can be obtained with this procedure by allowing the precipitate to settle overnight.

(5) This operation should be carried out in a fume cupboard.

APPENDIX II

Constitution of the Sub-Committee at 31st December, 1952

B. BAGSHAWE (*Chairman*)	Brown-Firth Research Laboratories
C. D. ATKINSON	Sheffield Testing Works, Ltd.
J. W. FLINT	Wm. Jessop and Sons, Ltd.
L. E. GARDNER	Edgar Allen and Co., Ltd.
C. L. GRAYSON	English Steel Corporation, Ltd.
E. W. HARPHAM	Richard Thomas and Baldwins, Ltd.
S. HARRISON	Kayser, Ellison and Co., Ltd.
J. D. HILL	Bragg Laboratory, N.O.I.D.
G. M. HOLMES	London and Scandinavian Metallurgical Co., Ltd.
R. T. POSTLETHWAITE	Samuel Fox and Co., Ltd.
L. N. TAYLOR	Samuel Osborn and Co., Ltd.
J. L. WEST	Hadfields, Ltd.

The Sub-Committee acknowledges the valuable assistance received from the following past members :

E. DYKE	Brown-Firth Research Laboratories
W. T. ELWELL	I.C.I. Ltd., Billingham Division.

Table III

VARIATION OF PRECIPITATION CONDITIONS

Acid Concentration:	**Copper Found**
1. Volume at precipitation 200 ml., 10 ml. of potassium thiocyanate (10%) added	
5 ml. H_2SO_4 (1:4)	**Precipitation of iron occurred**
10 „ „	**0·072%**
15 „ „	**0·085%**
25 „ „	**0·086%**
2. Volume 400 ml., 15 ml. of potassium thiocyanate (10%) added	
5 ml. H_2SO_4 (1:4)	**Precipitation of iron occurred**
10 „ „	**0·076%**
15 „ „	**0·085%**
25 „ „	**0·087%**
35 „ „	**0·072%**
Temperature at Precipitation Stage:	
60° C.	**0·085%**
80° C.	**0·084%**
Boiling point	**0·085%**
Hydrochloric Acid (sp. gr. 1·16):	
15 ml. HCl	**0·086%**
25 „ „	**0·037% (incomplete sulphite reduction)**
35 „ „	**0·075%**
50 „ „	**0·041%**

applied to the four steels that were first examined by the three operators, and the following results were reported:

Cu 1	0·20–0·202%	of copper
MGS 63	0·172–0·18%	„ „
MGS 151	0·090–0·092%	„ „
MGS 166	0·17–0·178%	„ „

Agreement between these two sets of figures is good, although there is a tendency for the above results to be slightly low; this was thought to be associated with the solubility of the cuprous thiocyanate. An interesting feature of this method, using potassium thiocyanate, is that it gives a complete separation from vanadium; this was later confirmed by successful application of the method to a sample of ferro-vanadium.

VARIATION OF CONDITIONS OF PRECIPITATION

To study the effect of varying certain conditions (*e.g.*, acid concentration and temperature at the precipitation stage), a steel sample of undisputed copper content (0·088%) was next examined. Replacement of sulphuric acid by hydrochloric acid was also included in the experimental work. The results shown in Table III indicate that the conditions specified in the tentative thiocyanate procedure need no further modification.

Experiments were also conducted on 5-g. samples of iron with 0·040% of added copper (which gave 0·041% Cu when precipitated with sodium thiosulphate). The copper from these samples was precipitated with varying amounts of potassium thiocyanate, the volume in each case being 400 ml. after addition of the reagent.

From the results in Table IV, it would seem that without some modification the quantitative precipitation of copper is impossible, although in the range 10–15 ml. of 10% potassium-thiocyanate solution the loss is only of the order of 0·002% Cu. The Sub-Committee therefore considered that the procedure should, at this stage, be applied to five of the steels given in Table I; the results obtained are shown in Table V.

This table shows that the average results are almost identical with those obtained using thiosulphate (*cf.* Table II), and also that a higher reproducibility is obtained.

Table IV

EFFECT OF THIOCYANATE CONCENTRATION

Amount of 10% Thiocyanate Added, ml.	Copper, %	
	Recovered	Lost
2·5	0·038	0·003
10·0	0·039	0·002
15·0	0·039	0·002
30·0	0·035	0·006
45·0	0·029	0·012
60·0	0·018	0·023
100·0	0·000	0·041

Table V

COPPER CONTENT OF STEELS, %
(Thiosulphate Method—App. I)

Operator	*MGS* 63	*MGS* 111	*MGS* 151	*MGS* 166	*MGS* 167	*MGS* 188
1	0·17 0·17	6·44 6·50	0·089 0·089	0·18 0·18	0·13 0·13	
2	0·175 0·175	6·48 6·48	0·09 0·09	0·18 0·175	0·13 0·13	
3	0·172 0·172	6·45 6·45	0·09 0·09	0·18 0·178	0·13 0·125	5·90 5·93
4	0·172 0·174	6·49 6·47	0·087 0·083	0·178 0·181	0·129 0·129	
5	0·17 0·17	6·44 6·45	0·09 0·09	0·18 0·18	0·12 0·13	
6	0·174 0·176	6·48 6·48	0·092 0·094	0·178 0·18	0·13 0·13	5·95 5·94
Range	0·006	0·06	0·01	0·006	0·01	
Avges.	0·172	6·47	0·090	0·180	0·128	

CONCLUSIONS

The method given in B.S.1121,[2] with minor modification, can be applied successfully to highly alloyed steels. Reduction and hydrolysis with sulphurous acid serves to remove interfering elements. Copper can be subsequently precipitated with sodium thiosulphate, but difficulties are introduced in the handling of the ignited precipitate; this, however, can be overcome by precipitation of the copper as thiocyanate.

The proposed method introduces no new complications and overcomes interference due to vanadium.

Molybdenum does not interfere. The only weakness of the method is the slight solubility of cuprous thiocyanate. This becomes significant when the copper content is under 0·1%, and precipitation with sodium thiosulphate in place of potassium thiocyanate provides more accurate results in this range.

References

1. " Copper in Permanent Magnet Alloys ": British Standard 1121, Part 5, 1948.
2. " Copper in Carbon and Low-Alloy Steels ": British Standard 1121, Part 14, 1949.

APPENDIX I

Recommended Method for Copper Determination

Solutions Required

Sulphurous acid

Ammonium hydroxide (1:1)

Sulphuric acid (1:99)

Sodium sulphite (25%)

Sulphuric acid wash—1 litre of H_2SO_4 (1:99), 10 ml. of sodium-sulphite solution (25%), and 5 ml. of potassium thiocyanate solution (20%).

Nitric acid (1:1)

Sulphuric acid (1:1)

Potassium iodide (60%)

Potassium thiocyanate (20%)

Starch (1%)

Standard sodium thiosulphate. Dissolve 4 g. of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) in water containing 0·1 g. of Na_2CO_3 and dilute to 1 litre. 1 ml. is approximately equivalent to 1 mg. of copper.

Standard copper solution. Dissolve 1 g. of pure copper in 10 ml. of water and 5 ml. of nitric acid (sp. gr. 1·42), boil, cool, and dilute to 1 litre.

Procedure

Dissolve 5 g. of sample (*see* Note 1) in 50 ml. of hydrochloric acid (sp. gr. 1·16), oxidize with nitric acid (sp. gr. 1·42), and evaporate to dryness. Add 30 ml. of hydrochloric acid (sp. gr. 1·16) and evaporate to 20 ml. Add 100 ml. of hot water, 100 ml. of sulphurous acid, boil, and filter through a paper-pulp pad (Note 2). Wash with sulphuric acid (1:99) and collect the filtrate and washings in a 600-ml. squat beaker. Warm to 70° C. (Note 3), add ammonium hydroxide (1:1) until a faint permanent precipitate appears, redissolve this precipitate with sulphuric acid (1:1) and add 5 ml. excess. Add 40 ml. of sodium-sulphite solution (25%), 10 ml. of potassium-thiocyanate solution (20%), and boil for 2 min.

Cool the solution to room temperature (Note 4), filter through a paper-pulp pad, and wash with sulphuric-acid wash. Dissolve the precipitate through the pad into the original beaker with 40 ml. of nitric acid (1:1) (Note 5) and wash with hot water.

Add 3 ml. of sulphuric acid (1 : 1), evaporate to fumes, cool, and add 10 ml. of water. Add 0·5 g. of sodium fluoride, neutralize with ammonium hydroxide (1:1), cool, acidify with glacial acetic acid, add 1 ml. in excess, and again cool. Add 5 ml. of potassium iodide (60%) and titrate with sodium-thiosulphate solution until the brown colour is almost discharged. Add 2 ml. of starch solution, 10 ml. of potassium thiocyanate solution (20%), and titrate until the blue colour is discharged.

Standardize the sodium-thiosulphate solution against 25 ml. aliquots of the standard copper solution treated as in the last paragraph.

Notes

(1) For copper contents greater than 0·25% use a 2-g. sample, for those greater than 0·5% use a 1-g. sample, and for those greater than 1·0% use a 0·5-g. sample; where necessary use a suitable aliquot of the solution.

Replicate results on a 5-g. sample should be within ± 0·005% of copper.

(2) If tungsten, tantalum, or niobium are present, allow to stand for at least 1 hr. before filtering.

(3) When the copper content is below 0·1%, greater accuracy can be obtained as follows:

Boil and add cautiously 15 g. of sodium thiosulphate ($Na_2S_2O_3.5H_2O$). Boil for 10 min., filter through a Whatman No. 540 filter paper, and wash well with water containing a little hydrogen sulphide. Dry the paper and precipitate in a silica crucible and burn off carbonaceous matter below 550° C. Cool, dissolve in 5 ml. of nitric acid (sp. gr. 1·42), and transfer to a small beaker. Add 3 ml. of sulphuric acid (1:1), and proceed as in the third paragraph of ' Procedure.'

(4) When the copper content is below 0·1%, improved accuracy can be obtained with this procedure by allowing the precipitate to settle overnight.

(5) This operation should be carried out in a fume cupboard.

APPENDIX II

Constitution of the Sub-Committee at 31st December, 1952

B. BAGSHAWE (*Chairman*)	Brown-Firth Research Laboratories
C. D. ATKINSON	Sheffield Testing Works, Ltd.
J. W. FLINT	Wm. Jessop and Sons, Ltd.
L. E. GARDNER	Edgar Allen and Co., Ltd.
C. L. GRAYSON	English Steel Corporation, Ltd.
E. W. HARPHAM	Richard Thomas and Baldwins, Ltd.
S. HARRISON	Kayser, Ellison and Co., Ltd.
J. D. HILL	Bragg Laboratory, N.O.I.D.
G. M. HOLMES	London and Scandinavian Metallurgical Co., Ltd.
R. T. POSTLETHWAITE	Samuel Fox and Co., Ltd.
L. N. TAYLOR	Samuel Osborn and Co., Ltd.
J. L. WEST	Hadfields, Ltd.

The Sub-Committee acknowledges the valuable assistance received from the following past members:

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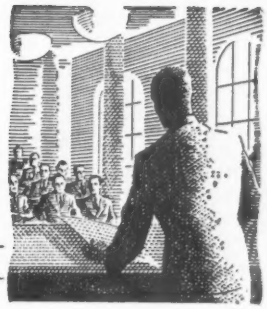
W. T. ELWELL	I.C.I. Ltd., Billingham Division.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

ANNUAL GENERAL MEETING, 1953

THE ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Thursday and Friday, 30th April and 1st May, 1953, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. Captain H. LEIGHTON DAVIES, C.B.E., the Retiring President, was in the chair at the beginning of the meeting, and later his place was taken by Mr. JAMES MITCHELL, C.B.E., the new President.

Sessions were held at 9.45 A.M. and 2.30 P.M. on the Thursday and at 10.0 A.M. and 2.30 P.M. on the Friday, a buffet luncheon being provided on both days in the Library of the Institute.

The Report of the Meeting was published in the July issue of the Journal.

Discussion on the Paper—

DEVELOPMENTS IN THE ROLLING OF BROAD FLANGE BEAMS AT THE CARGO FLEET IRON COMPANY, LTD.

By G. Barry Thomas

Mr. **G. Barry Thomas** (Cargo Fleet Iron Company, Ltd.) presented his paper.

Mr. **B. Chetwynd Talbot** (Cargo Fleet Iron Co., Ltd.): Our present method of rolling broad flange beams is not perfect and can be improved, but, as we had the facilities available for the immediate production of the broad flange beam section, we tackled it in that manner. I hope that it has given something to the industry at an earlier date than would otherwise have been possible.

Mr. **J. McLaughlan** (Appleby-Frodingham Steel Company): Mr. Thomas reports a very fine achievement in producing joists, or beams for that matter, with a 12-in. flange in a mill of the conventional 2-high type. I am particularly impressed by the method of passing the bar between two of the stands so as to reach the correct side of the mill. I agree with the author that it is impracticable to pass the bar through any of the available passes more than once.

On page 113 of the paper, reference is made to the necessity of cutting a bloom of 15½ in. × 7⅛ in. on the flat. What are the objections to shearing on the flat? When the roll centres were increased, was the diameter of necks also increased? The author has quoted a yield of 90% from bloom to finished section; would he say what the yield is from ingot to finished section, as this figure would provide a better comparison? Is there a large crop end or is the width of flange allowed to pass below its nominal size of 12 in.? Owing to the lack of taper in the closed flanges, is a lubricant used, or is the ordinary method of stripper guards relied upon?

Have roller-straightening machines been considered satisfactory for cold straightening? The difficulties in respect of the parallel flanges will be appreciated.

It is apparently the intention to produce 30 in. × 12 in. beams with the addition of only one other stand. Is it proposed to enlarge the roll-barrel length, and, if not, is one additional stand enough? Will it be possible to arrange for two 30-in. passes in each of the roll positions, thereby leaving the necessary amount of barrel length to provide for three collars?

Will the quality of finish compare favourably with that which should be obtained from the universal mill which is being installed in this country?

Finally, has it been considered practicable to roll the smaller sizes of broad flange beams up to, say, 10 in.

* *J. Iron Steel Inst.*, 1953, vol. 173, pp. 113–118.

× 10 in. in the conventional type of 2-high mill without making use of the vertical rolls ?

Mr. **E. L. Burgess** (Appleby-Frodingham Steel Company): Considering the possibility of buckled webs on these big beams, I should like to ask the author whether any such trouble is experienced. We always find some tendency for this in sections of this kind.

In the layout for 12 in. × 12 in. beams shown in Fig. 3, the last pass in the third stand, No. 12, is shown as being 12¼ in. wide, with the finishing pass set at 12 $\frac{7}{32}$ in. Assuming that these sizes are for new rolls, and that this will give approx. 12⅛-in. width of finished section, it would be interesting to know what happens when the rolls reach the end of their lives and the No. 12 pass becomes, say, 12⅜ in. wide, and the finishing pass becomes approx. 12 in. Will these conditions tend to produce buckled webs ? Again, the webs may buckle with the wider beams by the contraction of the flanges on the cooling bank. Does this happen, and can anything be done to counteract it ?

Regarding the layout of the design for the 24-in. beams, would not manipulation time be saved by working straight forward in the 2nd and 3rd positions and then running the bar back between the stands ? In the 12-in. design three passes are run with open flange to open flange and closed flange to closed flange, and I do not doubt that two passes of 24 in. would go the same way. Was this method tried originally and abandoned for some reason ? The question of wing or double collars would not arise in these circumstances.

The author stated that usually each motor drives two pairs of rolls, and apparently this is the case with the 24-in. beams. Would not the output be improved if the roughing-end motor drove only No. 1 stand, which has nine passes, and the finishing-end motor drove the other stands, which have, altogether, only five passes ? This would provide a more balanced arrangement, and I assume that the slack pass could be taken between Nos. 1 and 2 stands.

AUTHOR'S REPLY

Mr. **G. Barry Thomas** (in reply) : Mr. McLaughlan's first question was about shearing on the flat. We thought that by shearing on the flat we should have considerable trouble, due firstly to the shear cut and secondly to the necessity of charging the bloom on its flat into the wash-heating furnace and so having a cold surface on the side and not on the top or bottom. I explained in the paper that at first we did have a bloom sheared on its edge at about 15½ in. high ; but we now make a bloom 16 in. wide, turn it down, and shear it on its flat, and we have not had any of the troubles that were at first expected.

We have made no alteration in the roll-neck diameter ; it is still 18½ in., and it was not increased for beam rolling. We have put liners under the movable housing feet to get the correct delivery from the rolls on to the moving tables ; otherwise we should be working off the first roller of the moving table.

In regard to the yield, we bring about 90% of the ingot into the finishing mill. The saleable yield on the smaller sizes is about 80–82% ; on the larger sizes, up to 24 in., it is 77–78%. We do not need to take any longer crop than that on an ordinary joist. The flanges retain their length up to 1–2ft. from the end of the bar, so that there is no excessive crop ; they do not tend to run off on the front or back ends of the bar, but retain their width up to the crop.

For stripping the stock from the roll, we do not use any lubricant, except an abundance of water, and we now have no trouble. We had trouble at first until the flange delivery guides were made in forged steel of 0·35% carbon, which is stronger than the steel normally used in the mill.

To the author's knowledge no broad flange beams have so far been roller straightened, all this work being done by heavy-side press machines similar to those at Cargo Fleet. As a beam would have to be straightened in the roots, distortion of the flanges would take place, and side rollers would therefore have to be incorporated in the machine to overcome this. The cost of building such a machine would be very great, and, as the gag straightening of beams can be done so satisfactorily, the cost of building a roller-straightening machine would require earnest consideration before the large capital cost could be justified.

I do not know yet whether we shall produce a 30 in. × 12 in. or a 30 in. × 10½ in. beam. Even with the 5th stand, we have not enough roll-barrel length to roll a 30-in. wide beam with a straight web, and we shall therefore roll it with the web as a **W** formation, so that the width of the 30-in. beam through the train will be that of a 24-in. beam. On the penultimate pass we shall increase the width by about 2 or 3 in., and in the final pass we shall increase it again to the final width.

The quality of the finished beam is very good. I have no experience of the quality of beams produced in a Grey mill, but I would say that the quality of the finish in a 2-high mill such as ours would be a little better than that obtained in a Grey mill.

I think that a beam of, say, 10 in. × 10 in. could be produced without a vertical roller, provided that there was two or three degrees of taper in the flanges, but I do not think that it would be possible to produce flanges without taper without using a vertical roller. The penultimate pass has two or three degrees of taper, so that the flanges are not parallel: the vertical rolls correct this.

In answer to Mr. Burgess, we have no more—in fact, probably fewer—buckled webs than one normally gets in the production of a joist. It is possible to get buckled webs through the finishing pass when the operator starts with the first position too high and the finishing position too low, but normally we get very little buckling through the train. When the width on the penultimate pass is 12¼ in., as against the finishing, which, when new, may be 12 $\frac{7}{32}$ in., the flanges are not straight up and down, and therefore in each dressing they can be brought back to the correct width. We have no trouble in producing a perfect section, even though the finishing pass is turned down, owing to dressing, to 12 in. or even less. The vertical roll seems to correct any increase in width that would normally be expected.

I explained earlier that on the larger sizes we did attempt to repeat through the same hole, and there was trouble in that the delivery guides were knocked out. Eventually this method was abandoned and we repeated between the second and third position housings. The latter method is very quick with the moving tables—in fact, quicker than attempting to repeat in the same pass.

With our two motors we drive two and two, and Mr. Burgess suggests that we should drive one from the roughing end and three from the finishing end. We could do that, but there is a strain on the finishing when two other stands are driven, especially roughing stands which take quite a considerable amount of work, particularly when hard grey-iron rolls are used in the finishing. Secondly, we cannot repeat between the first and the second positions, because the first-position front side is a fixed table, and therefore it is impossible for the moving table to move far enough across the mill to take the bloom between the first and second positions ; we must therefore repeat between the second and third positions.

Joint Discussion on the Papers—

TRAIN ARRIVALS, HANDLING COSTS, AND THE HOLDING AND STORAGE OF RAW MATERIALS*

By M. D. J. Brisby and R. T. Eddison

RAILWAY TRAFFIC OF THE APPLEBY-FRODINGHAM STEEL WORKS†

By E. R. S. Watkin

Mr. **R. T. Eddison** (British Iron and Steel Research Association), who in the absence of Mr. Brisby owing to illness presented the first paper, mentioned that as the paper had been written some time ago it contained no reference to the new 27-ton ore wagons developed as a result of collaboration between British Railways and the Transport Committee of the British Iron and Steel Federation.

Mr. **E. R. S. Watkin** (Appleby-Frodingham Steel Company) presented the second paper.

Mr. **W. McLester** (Stewarts and Lloyds, Ltd.): Steelmaking consists of many important factors; an almost exclusive emphasis has hitherto been put on the technical and physical-chemistry side, but in modern steelmaking one of the essential factors is the handling. Traffic has only recently become a subject for detailed consideration, and logical and scientific studies such as these are valuable, both in designing layouts for new plant and in improving the traffic arrangements in existing works.

Mr. Watkin's detailed account of Appleby-Frodingham railway traffic is of the greatest interest. From one point of view we are in a similar position; Corby now produces 14,000–15,000 tons of iron per week, which means that over 40,000 tons of material has to be provided for the ore preparation plant and 12,000 tons of sinter has to be handled. The total number of wagons handled out of the works has increased from 392,000 in 1948 to 501,000 in 1952, owing to new sections of plant and increased production. Over the same period the blast-furnace output has increased by about 50%, and the figure for slag ladles hauled has risen from 175,000 to 204,000, even though the ladle size has increased.

Effective lighting is very important in iron and steel works, where traffic is mainly controlled by visual means. What are Mr. Watkin's views on the use of high floodlights ?

At Corby we run 30 locomotives, including two Diesels. We have examined the subject of Diesel locomotives in detail, and from actual figures on our two existing locomotives (one 200-h.p. Diesel-hydraulic and one 400-h.p. Diesel-electric), we are convinced that large savings can be made by using Diesels. This conclusion has been confirmed by other works. The advantage of Diesels in minimizing smoke nuisance, although not of primary importance, is worthy of consideration.

Radio-communication is still in the experimental stage in the U.K., and results show that with the present apparatus its scope is extremely limited. The full benefit of radio telephony will not be obtained until a transmitter is available that is compact enough to be carried in comfort by a pedestrian.

The recruitment of future traffic personnel is important in maintaining traffic efficiency. Unfortunately the right type of young shunter is not attracted by shift work, and the wages offered are often below those paid in the production departments, so that the men who are ultimately responsible for the efficient execution of the work tend to fall below the desired standard.

The fact that most existing works have a far from perfect layout must be accepted in considering siding capacity. Nevertheless, the theoretical principles laid down in the paper by Brisby and Eddison focus attention on certain traffic matters, improvements in which, whether by track modification, site alterations, or even a better form of administrative control, will result in saving time and money.

The control system at Corby is based on a daily standage figure for each commodity, fixed by the General Manager. A report sheet is submitted each morning showing the actual standage compared with that laid down, and any appreciable deviations are investigated by the Traffic Department in conjunction with the appropriate plant manager. Where any change is found to be necessary, the Buying Department are asked to make the necessary alterations in the future supply. This system, which is essentially flexible, has worked very well, and although the number of wagons handled has greatly increased over the last few years, the standage charges have been maintained as before, or even reduced.

Have the authors applied the formula given in Appendix II for the balance between stock on wheels and ground stock for a given commodity to any of the works they have visited, and has such application led to any change in practice ? The question is largely governed by judgment and experience, together with a consideration that is national rather than local, *i.e.*, the need to ensure quick turn-round of wagons. This formula cannot be applied to every commodity, owing to the varied factors involved. Although at a particular works it may be economical to hold stock in wagons, preventing the wagons from serving the rest of the industry may mean that the local saving is offset by supply shortages, with consequent production losses at works elsewhere.

The supply of coal for coke ovens is a problem in that large stocks have to be carried to cover seasonal fluctuations. There is a definite deterioration in quality as a result of long stacking times, and the new system of colliery holidays aggravates this position. It is important to reconcile these opposing factors, and the provision of a coal bedding and preparation plant goes some way to afford such a solution.

The figures in Appendix I for the cost of track maintenance and repairs per mile per annum compare fairly well with our figures at Corby, ours being slightly less.

Mr. **A. J. Harby** (Steel Company of Wales, Ltd.): Mr. Watkin does not mention the problem of where road haulage and rail can meet in the iron and steel works. These can be complementary, and the lorry is an economical and time-saving method of moving the smaller, urgently required loads, particularly the engineering requirements. It can also handle the disposal of slag, owing to the flexibility that results from its use. There is also the increasing tendency to despatch steel products,

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 171–183.
† *Ibid.*, 1953, vol. 173, pp. 1–15.

particularly sheet, by road, owing to customers' preferences. Where there is a tendency to turn over from rail to road, the combined road-rail dock for loading is a menace.

My Company has been using wireless for about two years, and for specific traffics, particularly where ingots are being delivered from two or more melting shops to a common stripper bay, it is invaluable. This traffic is controlled by one man on the shift, who is in complete telephonic communication throughout the shift with the melting shops, the mould bay, and the steel planner in the soaking pits; he can direct his locomotives to deal with the varying requirements that arise in an open-hearth process. Without wireless more men and more locomotives would be needed. We also use wireless for traffic, where it is undoubtedly an asset, but the cost of the installation would not be justified unless there were a primary commitment, such as we have on the ingots, which justifies the initial layout. With traffic wireless does not do away with the man on the ground.

We are at the moment running a fleet of steam locomotives and also a fleet of Diesels. Seven or eight years' service are needed before a true cost of maintenance can be obtained. However, in the 2½ years for which we have had the Diesels working (excluding manning from the running costs), the advantage of the Diesel over the steam locomotive is about 10*s.* per loco. hr.

Mr. Watkin has set out very clearly the advantages in availability, and he has tried to make a true comparison between the steam locomotive and the Diesel by comparing a 16-in. steam locomotive with a Diesel of about 300 h.p. That is fair up to 7 or 8 m.p.h., but after that, owing to the extra availability in the boiler, which can be 'flogged' for short periods, the Diesel begins to drop behind.

On the question of steam-locomotive availability, we are running at a greater down-time or a lower operating time than Appleby-Frodingham, and the paper confirms our feeling about one of the reasons. Out of 21 steam locomotives operating, we have 13 14-in. locomotives of about 28 tons weight, which are too small for the duty that they are now being asked to do, and which are therefore being overworked. Their scheduled repair cycle is 9–12 months, compared with 12–15 months for the 17-in. locomotives.

On our latest 0–6–0 steam locomotives, which have been running for just under two years, roller bearings have been fitted throughout, including the side rods. This has given a great saving in repair costs. Hardly any wear is visible on the side rods, and the piston bearings have not yet needed inspection.

Mr. **M. G. Bennett** (Operational Research Division, British Railways): I do appreciate the value of this work; it helps both the iron and steel industry and British Railways to have these joint studies.

Brisby and Eddison did not fall into a likely error when they examined the frequency of arrival of trains of scrap, coal, etc. A superficial examination might suggest that there was no planning behind railway operations. With an undertaking so complex as a railway there must always be so many random influences in operation that whatever statistic is taken there is bound to be some random fluctuation. There are obviously a number of factors over which we have no absolute control, such as the time of putting on rail of the traffics that have to be carried. Passenger trains have to be run when they are wanted, and other trains have to be fitted as well as possible in between. The net effect resembles the curve that would result from a completely random despatch of trains, but that does not mean that things are not planned so far as it is possible to do so.

In this confusing world a compromise must often be found between conflicting interests. In the matter of storage, the turn-round of wagons, etc., however, it would appear from this paper that it is in the interests of British Railways and of the iron and steel industry to do the same thing, and to reduce standage even below the free level. Again, if material is to stand in store for a long time as a buffer it should be unloaded rather than stored in wagons.

Some of the apparently conflicting evidence that exists on the question of steam *versus* Diesel locomotives may be explicable by the different loads to which they are put. Comparing fuel consumption with load, the characteristic curves of steam and Diesel locomotives differ, and some of the inconsistencies may disappear if differences in load are allowed for.

Mr. **M. F. Barnard** (British Iron and Steel Federation): Although one would not expect sidings to have been altered very much over the last seven or eight years, I find that the amount of home iron ore carried over British Railways has gone up from 6½ million tons in 1947 to 10½ million tons in 1952. How has that been dealt with? Has it been by keeping wagons under load or by the handling of traffic into store?

The standage scheme originated in an unusual way. The railways were trying to get much higher demurrage charges, and they had not appreciated the fact that there were, in effect, private railways in all the works. We had to go to the Minister to establish this principle of standage. We should therefore try to keep standage down as far as possible, because the higher the standage the more wagons are needed, and in the end the higher will be the price of transport.

There are now about 3000 27-ton wagons in operation. The larger hopper wagon has also come to stay, and about 85% of the hoppers on British Railways have a carrying capacity of at least 20 tons. The average loading of iron ore, over 90% of the loads, is about 20 tons for hoppers and 25 tons for the 27-ton wagons. That can be taken into account in establishing the relationship between the holding and reception sidings and what is put into stock.

There is to be a change in the loading of trains of 27-ton wagons. At the moment, with 50 13-ton wagons the load would be 650 tons, but with the 27-ton wagons there has been a limit of 378 tons. That is now to be raised to 675 tons.

No less than 90% of the home iron ore carried in this country is scheduled to a time-table, so that although there are random arrivals overall, there should not be so much of a random arrival of this particular traffic.

Mr. **C. Hulme** (Steel Company of Wales, Ltd.): A large steel company in the North of England has developed a 45-ton hopper wagon running on two axles. This is the largest load that can safely be dealt with in this way. The latest two-axle wagon at Appleby-Frodingham, in comparison with this, carries 31 tons, and the average for other steelworks is very much less. Is this 45-ton wagon likely to be a successful venture, and has Mr. Watkin thought of adopting it in his own works?

Double-track running only offers the advantage of separate up and down running in specialized cases, but it has the great advantage that, where there is congestion, through-trains can pass trains that are shunting, and many more trains can be handled without difficulty in any particular area. At the Steel Company of Wales, we have double-track running only on one set of tracks, and, with some alterations in the near future, that will be applied over one other section of the works tracks. It was never intended to be a general rule, although the layout of the works makes it look on paper as though

double-track running was the intention. Actually we have a series of long loops that are joined together.

The figures given in the paper for derailments seem to be rather high. At the Steel Company of Wales for the whole of 1952 they averaged 3·3 per week, made up as follows: defective rolling stock, 0·3; defective track, 0·5; operators' errors, 2·0; and unknown, 0·5. When the new Abbey Works came into commission, the derailments for the first few months were at an alarmingly high level, but they quickly came back to the average of the older works as the operators became accustomed to their jobs. In comparing these derailment figures, the number of locomotive shifts being operated must be borne in mind. At the Steel Company of Wales 72 shifts a day are operated, compared with about 112 at Appleby-Frodingham.

Lighting by towers is undoubtedly satisfactory in districts where fog and mist are absent. When a heavy fog descended on us recently for a few days, it was so dense that even the local lighting was rendered useless.

At Appleby-Frodingham power tipping of slag ladles has been rejected. At Margam a similar type of ladle is tipped by compressed air, the compressors being permanently sited on the slag bank, and this method has proved very satisfactory. There are three possible modifications of this method. The first is tipping by air compressor on a Diesel locomotive, *i.e.*, the compressor used for the brake gear; the second is tipping by a compressor carried on a car in front of the locomotive and travelling with each train; and the third is tipping by mobile compressor on the slag bank itself. We have used the third method only as an emergency method in the case of breakdown of the normal equipment. I believe that steam tipping of ladles fell out of favour at Appleby-Frodingham owing to heavy maintenance, probably as a result of condensation of steam in the pipes, cylinders, and valves.

Stocks that are not held in the various production departments are held and the stockyard is operated at the Steel Company of Wales in a very similar manner to that used at Appleby-Frodingham. The stockgrounds as at present laid out will probably hold about 200,000 tons, and handling is by Diesel mobile cranes, of which seven are in use at the moment. Stocks of scrap have now been concentrated near the melting shop at Abbey Works, and these dumps are under the control of the melting-shop management. The remaining materials in the general stockground are of the same types as at Appleby-Frodingham.

Until the new coke ovens were completed, coking coal was never held in ground stocks; reserves for the ovens then in operation were held in wagons to cover holiday periods. Coke-oven coal is held in six grades, but not in age-groups, as it is the practice to clear up the stock at each holiday time and start fresh stocks immediately afterwards. For the first time this year we shall hold on the ground up to 60,000 tons of coal, because of the miners' fortnight holiday. Hitherto 25,000 tons has been the maximum, and before the new coke ovens were built it was possible to hold an accumulation on wheels for the holiday period.

We are at present considering a new stockground, particularly for coal, to hold 100,000 tons of coking coal in two age-groups, with six varieties in each group. A travelling tippler surmounted by a small travelling grab crane would place the coal a sufficient distance from the tippler for bulldozers to push it forward into stock. With a stockground 200 ft. wide, three D8 bulldozers would be required under the busiest conditions. The travelling tippler would be of a type similar to that shown in the paper.

This type of tippler has also been considered for dealing with rubbish, but the use of a machine capable of tipping 1000 tons per shift for a present-day ash and rubbish disposal of 1500 tons per week is not economical, and so the existing system of using a machine with a pusher plate to empty 80% of the wagon contents is to be continued. All arisings of shale from the coal washery and of spoil from excavations made by contractors are handled by motor lorry. Where large quantities are involved, as from the melting-shop pit side during furnace demolition, 50-ton air dump cars are in use. We had until recently four of these, but we now have others coming into service; they are a very economical method of handling ballast in large quantities.

The iron and steel works of the future will use rail track and locomotives for handling the bulk production materials, but road transport will be used more and more for handling the smaller individual quantities of miscellaneous maintenance materials. A railway wagon should not be considered as a warehouse; congestion in the works is usually due to an accumulation of individual wagons, all supposed to be going to different destinations.

The **President** (Mr. James Mitchell): From our experience the difficulty in the use of Diesel locomotives is more likely to be in the boardroom than in the works, because capital cost is a consideration. On the question of road haulage, we have had recent experience of a successful changeover from wagon to lorry for the handling of flue dust from the furnace, and there must be many other places where that could be done.

AUTHORS' REPLIES

Mr. **Brisby** and Mr. **Eddison** (in reply): As Mr. McLester states, it is only in the last few years that traffic problems have become the subject of detailed studies in the iron and steel industry. One reason for this is that with increasing production greater tonnages had to be handled, often over existing steelworks rail systems, so that the operation of the systems had to be studied to ensure that they did not limit production. As Mr. Barnard points out, the tonnages for home ore alone increased by more than 50% between 1947 and 1952.

In answer to Mr. McLester, the formula put forward in the paper does not pretend to fit all cases of siding requirements, but, when applied to a number of works, the siding capacity given by the formula was found to agree with the capacities in a number of works whose sidings, evolved by a combination of trial and error and practical experience, appeared to result in satisfactory operation. It is therefore considered that the formula provides a measure which may be useful for making broad comparisons. The main purpose of the paper was to establish a basis for fixing reception and holding siding capacities and to suggest a policy for stocking and traffic operation.

We do not entirely agree with Mr. McLester's remarks about radio-communication. In the U.S.A. radio-communication between locomotives and a central control point is now apparently accepted as necessary to efficient traffic operation. Mr. Harby's comments on the use of wireless in his traffic department indicate that sets capable of giving good service are already available in the U.K. A number of papers prepared by B.I.S.R.A. are available on this subject.[1–4]

Mr. Bennett rightly points out that the fact of an apparently random distribution of train arrivals in time does not mean that there is no planning in the operation of British Railways. There are many reasons why deliveries from the railway cannot be completely regular; one of the most important is irregularity of deliveries to the railways by the consigner. The figures in the paper show this to be particularly noticeable with coal. The lesson from this is that anything that can be done by

British Railways or by consigners to regularize arrivals will greatly help steelworks managers.

The larger wagons mentioned by Mr. Barnard are a great improvement over the older types. Heavier trains, however, will complicate reception procedure in steelworks, although they may prove more economical to British Railways. Mr. Barnard's references to the standage scheme and to the need for rapid turn-round of wagons are widely accepted today in the iron and steel industry, particularly in times of wagon shortage. A previous B.I.S.R.A. report[5] deals expressly with this subject.

Holiday periods are not considered. The case of irregular weekly arrivals discussed in the paper is not intended to refer to them. If these periods are known in advance special arrangements can be made to deal with them.

Traffic problems in the iron and steel industry are more acute today than before the war. The paper will have served a purpose if it has contributed usefully towards a rational approach to the problem.

Mr. **Watkin** (in reply): At Appleby-Frodingham we had one area with high-level floodlighting, before the blackout, and we found very good penetration between wagons. There was the disadvantage, however, of no guidance during fog, in which multiple small lights continue to mark known positions after they cease to illuminate the ground.

Our attitude to the introduction of Diesel locomotives is that we intend first to obtain results from standardization now reached in our steam fleet and from an improvement of availability by the mechanization of bunker filling. Plant developments in the near future will displace most of our smaller steam locomotives, and our later requirements will then be for a standard Diesel type, of nearer 400 than 300 h.p., to operate interchangeably with our medium and larger steam types. Our rather intensive use of locomotives would reduce the hourly overheads for Diesel power, but this might also reduce the customary savings per hour, Diesel working costs being in close proportion to haulage effort, whereas steam working costs reflect this less closely.

Radio control of traffic has advantages for special purposes, *i.e.*, the transfer of hot ingots from widely spaced melting shops, but it is not generally an effective substitute for personal supervision.

The new Appleby-Frodingham four-wheeled ore wagons are of 31 tons capacity because gross weights of 40 tons have been permitted on a main-line branch leading to certain mines. It is hoped that main-line limits will be raised further in the future. Gross loads of 30 tons/axle are usual for metal ladles and 45-ton four-wheeled wagons should be satisfactory for special internal purposes. The new four-wheeled slag ladles, tilted by a short rope with pulley of easy radius, have the same capacity as many using steam or air power. They have the advantages of relatively low cost, more effective discharge of difficult skulls, and short overall length allowing maximum numbers in position at the furnaces.

The paper by Brisby and Eddison is a valuable enquiry into the factors that should determine wagon-standage ratios. The 1½-day period is a genuine, though difficult, target, calculated independently of the effective free inward time with which it coincides.

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Joint Discussion on the Papers—

THE QUENCH AGEING OF IRON*

By A. L. Tsou, J. Nutting, and J. W. Menter

EFFECT OF QUENCH AGEING ON STRAIN AGEING IN IRON†

By A. H. Cottrell and G. M. Leak

Dr. **J. Nutting** (Cambridge University) presented the first paper and Dr. **G. M. Leak** (British Iron and Steel Research Association) presented the second. Dr. Leak drew attention to the following alterations to the paper.

Table I gave a short calculation of the enhanced concentration of carbon atoms, in solution, in equilibrium with small precipitated particles of iron carbide. There was an arithmetical mistake in the fourth column. The correct figures, for increasing temperature of ageing, were $9{\cdot}5 \times 10^{-7}$, $2{\cdot}1 \times 10^{-6}$, $1{\cdot}5 \times 10^{-5}$, $1{\cdot}1 \times 10^{-4}$, and $5{\cdot}9 \times 10^{-4}$ respectively. These figures were smaller than the values in the Table and thus made the enhanced solubility even more negligible than was reported.

A calculation on the basis of the amounts of carbon and nitrogen that are expected to be in solution, from analysis figures, gave a ratio of 4·7 for the rates of strain ageing for material (*a*) freshly quenched and (*b*) quench aged at 200° C. The paper indicated (p. 305) that the experimental value for this ratio was 5; this error occurred during condensation of an earlier draft of the paper. The value 5 was correct for the ratio of the times taken to give complete ageing.

A third mistake arose in the calculation of the expected amount of solute needed to give strain ageing at the observed rates, based on the theoretical formula of Cottrell and Bilby. Unfortunately, in this calculation results in minutes were used in a calculation for seconds. The correct theoretical value then became about one-fifth of the experimental value. However, agreement to better than one order of magnitude could hardly be expected.

Dr. Leak apologized for these mistakes; none of them significantly affected the conclusions in the paper. He also pointed out that the work reported in the paper was a preliminary investigation to determine whether

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 163–171.
† *J. Iron Steel Inst.*, 1952, vol. 172, pp. 301–306.

the supposed effect of varying the concentration of carbon or nitrogen atoms really existed. The present results had qualitative rather than quantitative significance. The work was now being extended more systematically on material of controlled carbon or nitrogen contents and would provide a thorough quantitative check on the theoretical predictions. The preliminary nature of the present experiments was evidenced mainly by the use of a commercial iron containing both carbon and nitrogen.

Dr. **B. B. Hundy** (British Iron and Steel Research Association): One point that arises from the paper by Professor Cottrell and Dr. Leak seemed to me to be most interesting. Apparently, when a freshly quenched sample of iron is strained, all age hardening due to quench ageing is eliminated. This can be seen in Fig. 1 of the paper, where the rise in hardness on ageing of the freshly quenched material is about the same (about 20 points) as that of the quench-aged material. This implies that straining prevents the precipitation of iron carbide or nitride, the solute atoms preferring to remain in solution, presumably forming clouds round the dislocations. This conclusion is, of course, in agreement with the results of Andrew and Trent,[1] which are mentioned in this paper. One wonders, however, whether there is a limit to this effect. If a steel containing, say, 0·1% of nitrogen were quenched and then strained 1–2%, would this straining still prevent precipitation and hence eliminate the quench-ageing phenomena ? Perhaps Professor Cottrell or Dr. Leak could give a theoretical estimate of the amount of solute that could be retained in solution after such a treatment ?

It is interesting to compare this work with the earlier work of Davenport and Bain,[2] who used the Rockwell hardness test to follow strain ageing. Like the present authors, Davenport and Bain tested material in the as-quenched and quench-aged conditions. The ageing treatment was for 17 hr. at 100° C. The agreement between the results of the two sets of investigations is very striking. In the earlier work, quench ageing apparently increased the strain-ageing time by about 6–8 times (ageing at 20° and 80° C.), which figures compare closely with the figure of 7 times the speed, quoted in the present paper. The time to reach the maximum hardness, however, was 2–3 times greater than that taken to reach the maximum yield point in the present work. I have also plotted some of Davenport and Bain's figures for strain ageing at 20°, 40°, and 80° C. in terms of the parameter $(Dt/T)^{\frac{1}{3}}$. The scatter in these results is rather greater than that in the present work, but it is possible to obtain a comparison of the initial ageing rates for the material in the two conditions. I calculate that the initial ageing rate of the freshly quenched material was about 4·4 times that of the quench-aged material. I think that the close agreement between this figure and that of 5 times the rate, quoted by the present authors, is rather a coincidence, although the chemical compositions of the two irons might be similar. Unfortunately, Davenport and Bain do not give the nitrogen content of their steel, so that this point cannot be decided, nor can the theoretical ageing rates be calculated as they have been in this paper.

Do the authors consider that comparable results would be obtained if the material in the two conditions had different grain size—if, for example, the as-quenched material had a grain size of 8 and the quench-aged material had one of 5 ? Is the rate of ageing at a grain boundary—considered as an array of dislocations—the same as that inside the grain (which was, I believe, the model used by Cottrell and Bilby in the derivation of equation 5) ?

I notice that on p. 303 the authors state that in fully aged specimens the upper yield stress is constant and is not preceded by any detectable plastic deformation. Is this to be expected ? I was under the impression that, according to the theory, some slight plastic deformation took place inside the grains before catastrophic yielding set in. Would the authors comment on this ?

Finally, I am glad to see that the authors' work confirms the necessity of adding aluminium, vanadium, or titanium to stabilize the nitrogen and produce a non-ageing steel. In this connection I would also like to point out that the normal cooling rates used in industry are low enough to give a non-ageing steel, even without quench-ageing at a low temperature.

Mr. **C. Boulanger** (I.R.S.I.D., France): The paper by Professor Cottrell and Dr. Leak is very valuable from a general viewpoint. Quantitatively, it is necessary to bear in mind that the measurements of solubility at low concentration are not very precise. The composition of the iron was not the same in the Chicago work, mainly by reason of its content of manganese, which would have an effect on the solubility of carbon and nitrogen.

Secondly, the paper assumes that carbon and nitrogen have no mutual effect; but, as indicated in Fig. *A*, the solubility of carbon and nitrogen cannot be added at a given temperature. The quantity of nitrogen is a function of the quantity of carbon. Why was it not possible to make direct internal friction measurements to ascertain the solubility just before strain ageing ?

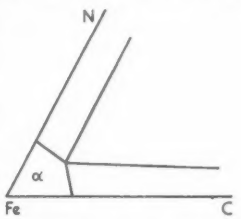

Fig. A—Part of ternary system of Fe–C–N, showing alpha phase

Mr. **W. P. Rees** (National Physical Laboratory): One of the most interesting findings of Dr. Tsou, Dr. Nutting, and Dr. Menter is the presence of austenite in the grain boundaries. From the calculation on p. 167, these authors seem to think that all the carbon and nitrogen which would not be in solution at 700° C. would have migrated to the boundaries. I do not think that this belief can be sustained, because the figure of the solubility at 700° C. has been largely determined by the experiment of heating carbon steels and quenching them. At the beginning of the paper the authors say that this treatment did not remove the carbide particles. It is therefore unlikely that all the excess carbon and nitrogen would have migrated to the boundaries. I think that the authors are right in believing that the austenite is essentially a nitrogen austenite and not a carbon austenite. The nitrogen eutectoid temperature is 590° C. and they found austenite even at 600° C. It would be interesting to know whether they could find it at 580° or 550° C.

The finding of the austenite in the boundaries is quite important. It is an effect which in some ways is contrary to our conceptions. The suggestion that this type of segregation to the boundary can occur has been made previously by McLean and Northcott.[3] From work at the National Physical Laboratory on high-purity irons we have shown[4] that oxygen seems to migrate to the boundaries. Its presence is shown up not as a discrete phase—it cannot be seen by ordinary microscopic methods—but by a very marked effect on the strength of the grain boundaries. We have found similar effects in iron–nitrogen alloys and iron–phosphorus alloys. We have not detected these elements in the boundaries but we can show their effect on the strength: the metal becomes quite brittle. This would seem to be rather a common and important effect. Examples are shown in

the brittleness induced by over-heating in alloy-steel forgings. Temper brittleness also seems to be caused by a similar migration to the boundaries.

The discussion of the possible sites that the carbon atom can take up in the cubic α lattice is important, as the properties of the resulting solid solution are largely governed by the manner in which the carbon is held in solution. The tetragonal martensite lattice is brittle: quenched steel containing more than about 0·15% of carbon must be tempered. If, however, an iron–carbon alloy containing 0·05% of C is quenched from 950° C., not only is it hardened by the carbon maintained in solution, but also the ductility, instead of being lowered, is greatly increased.

Dr. **M. L. Becker** (B.I.S.R.A.): In Fig. 3*b* of Dr. Nutting's paper, although it seems quite possible that the micrograph shows small platelets, as stated, the evidence is not convincing. It occurs to me that it might be worthwhile to attempt to separate the epsilon carbide plates electrolytically and to examine their shape, either directly by means of optical or electron microscopes or in some other way. The same would apply to the orthorhombic iron carbide, which appears on tempering above 200° C.

Bearing in mind the treatments that were given and the composition of the iron, it does not surprise me that appreciable amounts of austenite were found in the grain boundaries. I am perhaps on delicate ground, because I see that the iron used was obtained from the British Iron and Steel Research Association, but I wonder whether we could not have given Dr. Nutting material slightly more suitable for his experiments than he evidently managed to get. The quantity of impurities is rather high, particularly the nitrogen, and if a purer iron could have been used and carburized to about the same level of 0·02%, might that not have enabled Dr. Nutting and his co-workers to make some rather more specific conclusions from the results ?

Mr. **D. McLean** (National Physical Laboratory): There is one small experimental point relating to the kind of work that Dr. Tsou, Dr. Nutting, and Dr. Menter have reported. I suggest that picral is a more suitable etching reagent than nital. Nital etches crystals of different ferrite orientations at considerably different rates, so that grain-boundary ridges are somewhat masked by the step at grain boundaries, and when veining films and carbide particles are distinctly revealed in some grains they can barely be discerned in others. Picral, on the other hand, etches ferrite crystals of all orientations at much the same rate, so that its use avoids these difficulties.

The authors' interesting observation of austenite films of high carbon content calls to mind a somewhat similar observation made by Carpenter and Robertson,[5] who found that when two ferrite nuclei grew in the same austenite parent crystal, the interface where they met appeared to have a high carbon content, because, on quenching from just above A_1, this interface region etched like martensite.

The authors mention that after slow cooling the austenite films were not detected. However, ridges at both grain and vein boundaries are certainly observed after slow cooling, at least in some cases, and indeed are more prominent than after a more rapid cooling. If, after the latter treatment, the specimen is reheated and then cooled slowly, the films reappear in prominent form. Therefore, although the austenitic character of the ridges apparently disappears on heating below A_3, whatever it is that causes the ridges, as such, re-concentrates at the grain and vein interfaces during slow cooling, being apparently somewhat dispersed by reheating. This behaviour is to be expected if the ridges are due to locally high carbon (or nitrogen) concentration at these interfaces, which in turn is to be expected on energy grounds.

Dr. Nutting suggests one reason why his material aged more quickly than the material used by Trotter and myself.[6] Another possible reason is that our material was less pure, and the impurities may have retarded ageing.

Dr. Becker cast some doubt on the interpretation of Fig. 3*b*. In the work of Trotter, Clews, and myself,[7] we obtained a sequence of electron micrographs from specimens aged for increasing times at different temperatures. Although one micrograph alone might be doubted, when seen in the context of this sequence there could be little doubt that the mottled appearance shown in Fig. 3*b* was the prelude to a genuine precipitation.

Dr. **P. Samuel** (Hadfields Ltd.): I agree with Mr. McLean that picral is slightly more satisfactory in regard to its etching characteristic in revealing the grain-boundary and veining films in these irons, although nitric acid also has possibilities.

With regard to Dr. Becker's remarks, my own observation is that in the absence of carbon these grain-boundary ridges do not appear.

I have noticed that grain-boundary ridges were present in Armco iron after a variety of heat-treatments, including annealing. If these films are austenite, I am very curious to know why they do not transform to martensite and disappear that way; alternatively, why do they not spheroidize with lengthy anneals at a low temperature ? I wonder whether we might anticipate Dr. Ko's paper this afternoon and say that the main boundary film, as with the veining film, is actually coherent with the ferrite lattice, with the result that it is not exactly a separate phase ?

Professor **A. H. Cottrell** (Birmingham University): When considering the stability of phases at grain boundaries, particularly that of austenite, from the thermodynamical viewpoint, we should not overlook the work of Professor Cyril Smith[8] in America on grain-boundary energies. He has pointed out that in many systems the energy of a boundary between two different phases is lower than that of a boundary between similar phases. Thus, in iron the energy of a boundary between grains of austenite and ferrite is about three-quarters that of a boundary between two ferrite grains. As it is well known that in iron and low-carbon steels the free energies of austenite and ferrite are nearly equal at all temperatures, we can expect quite small effects to tip the balance one way or the other when considering the relative stabilities of these two phases, and it seems possible that one of these small effects might be grain-boundary energy. For example, at a place where three ferrite grains meet, the free energy might be lowered, even in the temperature range where ferrite is the stable phase, if a small amount of austenite were to form at the junction so that some of the ferrite/ferrite boundary there was replaced by an austenite/ferrite boundary. It would be useful to make a calculation of this effect to see whether it could account for the observation noted by Dr. Tsou, Dr. Nutting, and Dr. Menter.

AUTHORS' REPLIES

Dr. **J. Nutting** (in reply): Mr. W. P. Rees has commented on the formation of austenite at the ferrite grain boundaries. The aim in carrying out the calculation on the amount of carbon or nitrogen required to form the films was to discover whether a sufficient quantity of these elements would be present in excess of the amounts that are believed to be soluble in the ferrite. The calculations show that there is more than sufficient carbon and nitrogen, and therefore it is not surprising that a very small amount of carbide is also present at the ferrite grain boundaries.

It is unfortunate, as Dr. Becker remarks, that these experiments have not been carried out on purer materials, but at the time of the investigation the pure irons now being made at the National Physical Laboratory were not available. However, even with a purer material I do not think that different results on the decomposition of the supersaturated ferrite would be found.

Mr. McLean's evidence upon the nature and shape of the first-formed precipitates is in agreement with some further experimental evidence that we have obtained by electrolytic extraction of the carbides as suggested by Dr. Becker. In many cases the extracts were plate-like in shape. The electron-diffraction transmission pattern was that of a hexagonal cross-grating. However, this pattern was believed to arise from the conversion of the carbide to graphite and not to be that of the ε-carbide.

Mr. McLean's and Mr. Samuel's statements that picral would show ferrite grain-boundary ridges more clearly than nital are valid. But picral is a dirty etchant, in that etching products remain on the surface and these are difficult to remove by washing. When the specimen is to be examined by electron diffraction, a surface free from etch products is necessary; this may be readily obtained by etching with nital.

Professor **A. H. Cottrell** (in reply): Dr. Hundy raised an interesting point: would precipitation of the carbon be prevented by creating dislocations in the metal? Would the carbon go to the dislocations in preference? The experiments that Dr. Leak and I carried out were designed to prevent that kind of precipitation. We tried to arrange the number of dislocations and atoms in such a way that there was not enough carbon and nitrogen to go round among the dislocations. However, recently I heard of some work by Dr. Lücke, in Germany, in which it was arranged that there was an excessive amount of carbon and nitrogen in solution and there were not many dislocations; the ageing behaviour was followed by the electrical resistance method. It was shown that the $(Dt/T)^{\frac{1}{3}}$ relationship applied until a late stage, and it was inferred that the dislocations continued to pull in carbon and nitrogen atoms to themselves even after they had already gathered in large numbers. From the residual electrical resistance, it was concluded that when the carbon atoms became concentrated within the vicinity of the dislocations they actually precipitated. Thus, both processes seem to go on together; the dislocations pull in the carbon from long distances and when the carbon gets close it is actually precipitated.

Dr. Hundy has also asked whether the rate of ageing at grain boundaries would be the same as that within grains. Theoretically, one might expect it to be rather slower because the stress field from a grain boundary falls off rapidly with distance compared with that from a single dislocation. I believe that Dr. Bilby, in Sheffield, has been making calculations in this connection. Experimentally, we do not know very much. Dr. Leak made an isolated experiment using two different grain sizes and found no observable difference in the rates of strain ageing.

Regarding the existence of a slight plastic deformation before the upper yield point is reached, I agree entirely with Dr. Hundy that, theoretically, one might expect this. In practice, however, the amount that might be expected will depend upon the degree of axial alignment in the specimen. Our specimens were rather well aligned because, in the initial stages, each whole specimen was straightened plastically and not then removed from the machine. When alignment is made like that, we might expect the degree of plastic strain before the yield point to be small.

Monsieur Boulanger asked us why we did not use internal friction to measure the concentration of carbon and nitrogen in solution. At that time we did not have the apparatus. However, Dr. Leak is continuing with his experiments and now has such an apparatus, which will be used to measure the concentration in solution.

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DISCUSSION ON THE TRANSFORMATION OF AUSTENITE

This discussion was based on the following papers:

"The Formation of Bainite," *by T. Ko and S. A. Cottrell.**

"Effects of High-Temperature Heating on the Isothermal Formation of Bainite," *by S. A. Cottrell and T. Ko.*†

"Thermal Stabilization of Austenite in Carburizing Steels," *by H. M. Otte and T. Ko.*‡

"Line-Broadening of Martensite in Nickel Steels," *by R. A. Smith.*§

"The Deformation of Austenite in Relation to the Hardness Characteristics of Steel," *by G. R. Bish and H. O'Neill.*‖

Dr. **T. Ko** (Birmingham University) presented the first three papers; Dr. **R. A. Smith** (The Mond Nickel Co., Ltd.) presented the fourth paper, and Dr. **H. O'Neill** (University College, Swansea) the fifth paper.

Dr. **P. Samuel** (Hadfields Ltd.): In regard to the excellent photomicrographs in the paper by Dr. Ko and Dr. Cottrell, and especially to the convincing film produced by vacuum etching and hot-stage microscopy, I should like to ask whether the authors have any explanation for the tram-line etching effect of the grain boundaries especially noticeable in the En 21 steel of Fig. 7. The production of grain-boundary grooves by

* *J. Iron Steel Inst.*, 1952, vol. 172, Nov., pp. 307–313.
† *Ibid.*, 1953 vol. 173, Mar., pp. 224–228.
‡ *Ibid.*, Jan., pp. 31–35.
§ *Ibid.*, Feb., pp. 147–152.
‖ *Ibid.*, Apr., pp. 398–405.

vacuum etching is well understood, but there seems to be a suggestion of ridging at either side of the boundaries. Similar effects have been observed in Armco iron, and I wonder whether the ridging might be due to any alteration in the transformation characteristics brought about by the chaotic state of the lattice close to the grain-boundary region or to some other mechanism. In the same series of micrographs showing the growth of bainite plates, it seemed to me that the rate of growth along the habit planes could be used to calculate the activation energy of the process and further substantiate the authors' theory. A rough calculation gives an activation energy of 36,000 cal./g.atom, which corresponds to that of the diffusion of carbon in austenite. Obviously, if this is so, the process is not controlled by the diffusion of carbon in ferrite, nor does it apply to the thickening of the plates, which, as the authors indicate, is more likely to be controlled by carbide formation.

I am curious to know how supersaturated ferrite can be strain-free. This was mentioned in the review of previous theories of other authors, and I should be pleased to hear that this could be amended without affecting the theories !

Regarding the second paper, on high-temperature effects, I think the authors have made a valuable point in bringing out the effect of austenitizing temperature on the shape of the isothermal transformation curve. In En 25 they show the marked difference in shape for austenitizing temperatures of 835° and 950° C., thus emphasizing the dangers of applying a standard transformation diagram to material that has not been austenitized at exactly the quoted temperature of the diagram. However, I am unable to appreciate why, if the phenomenon is not general, an explanation based on sulphide inclusions is plausible. Surely such inclusions are not confined to Ni–Cr–Mo steels? Perhaps we might invoke the previous paper, where it is pointed out that carbide-forming elements hinder the carbon mobility, hence the growth of bainite. If these carbon-attracting elements outbalance the tendency for bainite growth, then transformation will be slow. High-temperature heating will tend to homogenize the structure and weaken the hindrance of carbide-formers, allowing a faster transformation. This could easily be tested by a study of the effect of time at austenitizing temperature upon the transformation rate. Has anything been done along those lines? Looking at the results, one wonders whether the molybdenum content itself might not be the decisive factor.

In the paper by Dr. Otte and Dr. Ko, I was interested to see that there was no evidence of an increased retained austenite content with increased austenitizing temperature in the nickel steel. This is contrary to Cohen's findings and the observations of the Russians and ourselves on similar steels. The Russians produced evidence to the effect that graphite was responsible, and we have obtained a little confirmation of this viewpoint. The latter steels were prepared from the melt, when graphitization would be promoted. In Dr. Ko's paper, the composition was attained by carburization at a much lower temperature, and presumably the graphitizing influence would not be so great and may, in any case, be offset by the chromium and molybdenum contents. It would be most helpful to know whether the authors observed any graphitization in their alloys.

In view of the high austenitizing temperature chosen, I am not surprised that the room-temperature stabilization had no effect with −79° C. as the reference temperature, because our data, which we hope to make available shortly, are to the effect that there is a decreasing rate of stabilization with increasing austenitizing temperature in a wide range of steels. It seems to me that, on quenching to room temperature, transformation to martensite sets in at many points and does not quite reach the critical condition to transform at many others. Holding at room temperature causes some lessening of the urge to transform, so that the impetus caused by cooling to 0° C. is insufficient, but cooling to −20° C. enables some parts of the austenite to pass this critical condition and to transform. Cooling to −79° C. produces a sufficiently large impetus to offset the original relaxation and equal that of the direct quench. Thus, there is only an exceedingly slow room-temperature stabilization effect in these steels under these conditions.

There is evidence to show that stabilization can occur on isothermal holding above M_s. If the specimen is held above M_s for long enough it transforms to bainite. Has the stabilization effect any connection with bainite nucleation or do the authors consider these to be independent mechanisms?

Mr. **K. R. Jastrzebski** (Quasi-Arc Company, Ltd.): The use of Meyer analysis in determining the hardness of metals can be of great importance, as Professor O'Neill has already shown in an explanation of ageing phenomena occurring in duralumin.

The work-hardening of 18/8 stainless steel and especially the products of subsequent heat-treatment are worthy of study. At one time I was given some stainless steel wire for examination. It contained 18·6% Cr, 7·9% Ni, 0·11% C, 0·52% Mn, 0·46% Si, and no Mo, Ti, or Nb ; it was readily attracted by a hand magnet and its hardness was 523 D.P.N. Although there was some suspicion that it might be of the martensitic type, a chemical analysis confirmed it to be of unstabilized 18/8 quality, and the microstructure, when etched with Kalling's reagent, consisted of pseudo-martensite which was rather pronounced. I was unable to obtain information regarding the amount of cold work caused by the drawing operation. However, I have calculated the M_s temperature to be about −168° C., and this figure, although only approximate, may indicate that the composition of this steel would be suitable for formation of martensite when plastically deformed.

Recently I was confronted with two fillet welds made on a ½-in. thick plate of En 100 quality steel containing 0·31% C, 1·37% Mn, 0·53% Cr, 0·17% Mo, and 0·97% Ni. In one case a ferritic type of electrode known for its low hydrogen content was used. In the other case a fillet weld was made using nickel–chromium austenitic armour-welding electrodes. The original D.P.N. of the plate before welding was 260 for the austenitic weld and 258 for the ferritic weld. The welding current, the gauge of the electrodes, and the geometry and size of the joints were identical in both cases. The heat-affected areas, being of the same size, indicated that the heat input into the joints could not have varied greatly. Microscopical examination carried out previously showed that the parent material was free from any segregation.

The D.P.N. (10 kg. load) of the heat-affected zone produced by the ferritic weld and taken 2 mm. from the interface was 442 ; that of the heat-affected zone produced by the austenitic weld was 536, giving a difference of 94 D.P.N.

These specimens were then heated for one hour at a temperature of 840° C. and oil quenched. Hardness determinations were made at points 2 mm. away from the weld/parent-metal interface. They were 480 D.P.N. near the ferritic weld and 532 near the austenitic weld, giving a difference of 52 D.P.N. All the hardness indentations and micro-examinations were made on the bottom component of the fillet.

The difference of 52 D.P.N. is appreciably smaller than that of 94 D.P.N. obtained previously with the specimens

in the as-welded condition. This might possibly be because an oil quench is much more severe than the quench that occurs during the welding operation when the specimens are small. In addition to this, or alternatively, it may be that a lower strain in the zone adjacent to the weld has resulted from the even heating of the heat-treatment as against the localized heating during the welding operation, where additional straining might take place, this being affected in both cases by the greater contraction of the austenitic weld.

The examination under the microscope showed that the microstructure near the austenitic weld consisted of slightly more martensite than that near the ferritic weld. The remainder of the structure was composed of lower bainite. Both specimens were then tempered for one hour at 630° C., and the hardness was 299 D.P.N. near the austenitic weld and 296 near the ferritic weld.

At the time of obtaining these results, the assumed explanation for the differing structures and hardnesses was that they were due to differing strain conditions occurring in the austenite of the heat-affected zone before transformation. This paper has confirmed that my explanation is correct.

As I have already mentioned, with 18/8 stainless steel there might be two temperatures, M_s and M_d. To what extent do the authors think that the temperature of the M_s and M_f lines might be affected by the variable deformation of austenite?

It seems to me that austenite in the heat-affected zone of a weld may be strained over a long range of temperature. Do the authors contemplate any work to determine the upper limit of temperature at which deformation could alter the rate of transformation?

Mr. **G. Mayer** (Mond Nickel Company, Ltd.) : I have recently examined the formation of bainite in an En 23 steel and I generally agree with the views expressed by Dr. Ko and Dr. Cottrell on the mode of its formation. Their hot-stage microscope results have provided a convincing answer to the question of whether the bainite reaction proceeds by nucleation and growth or whether the plates are fully formed in a very short time, as in the case of martensite. One difficulty with the latter theory was that, whereas lower bainite has the acicular form associated with the shear type of reaction, upper bainite is not usually acicular, except in the early stages of formation, and it seemed that two different mechanisms of formation would have to exist to explain the difference in appearance of the two types of bainite. This seemed unlikely, particularly as no sharp change in transformation characteristics could be detected with decreasing temperature of bainite formation.

From my own studies I have formed the impression that the mechanism of bainite formation is the same at all temperatures, with the bainite tending to form as plates by growth along preferred planes. The plate-like form is retained in lower bainite because the rate of growth normal to the plate, compared with that at the plate edges, is relatively small ; but in the case of upper bainite, although the initial crystals tend to be plate-like, the rate of growth normal to the plate is higher, and this leads to the destruction of the plate-like form, so that the final product is composed of irregular-shaped crystals. The plate-like form of upper bainite may be retained, however, if closely adjacent parallel sets of plates are formed, thereby restricting growth except at the plate edges. This type of bainite is often described as 'feathery' bainite. Dr. Ko has also referred to the precipitation of carbide between the ferritic plates in the formation of this type of bainite.

The authors found that partial exposure of an En 31 steel sample at lower-bainite temperatures promoted subsequent reaction at upper-bainite temperatures. I have also found that this occurred in an En 23 steel, but when the reverse treatment was applied—holding at upper-bainite temperatures for a time and then quenching to lower-bainite temperatures—no effect was found. When the initial treatment was sufficiently long to allow a small amount of upper bainite to form, the lower-bainite plates that were formed during the second stage appeared to nucleate preferentially at the upper-bainite crystals, but the incubation period for their formation was not significantly affected.

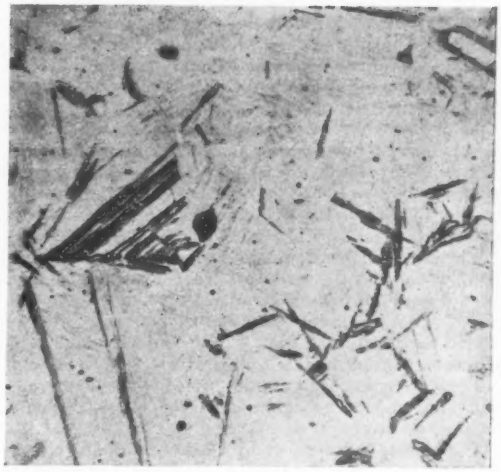

Fig. A—En 23 steel, showing plates of light-etching upper bainite formed at 475° C. × 750

The micrograph shown in Fig. *A* is taken from a sample of the En 23 steel in which a few plates of light-etching upper bainite were allowed to form at 475° C. The sample was then quenched again to 320° C. and some plates of dark-etching lower bainite were allowed to form. Apart from the tendency for the lower bainite to nucleate at the upper-bainite crystals, it is interesting to note that the habit planes of both types of bainite seem to be the same. This further supports the view that the mechanism of formation of bainite is the same at all temperatures.

Professor **F. Wever** and Dr. **A. Rose** (Max-Planck-Institut für Eisenforschung) (read by Dr. Ko) : The paper by Dr. Ko and Dr. Cottrell supplies very clear experimental evidence that the bainite transformation takes place by nucleation and coherent growth. In spite of this, the process of nuclei formation must be similar to that of the 'Umklappung' mechanism in martensite formation, as it causes the same deformation of the surface.

The two hypotheses for the theoretical considerations of the beginning of the bainite transformation below M_0 and above M_s are the reduction in the carbon content of the ferrite (*a*) by the diffusion of the carbon into the austenite or (*b*) by precipitation as carbide. The first of these has received good experimental confirmation in Germany in the paper by Schrader and Wever.[1] The electron micrographs of a manganese steel, transformed at 475° C.—*i.e.*, in the upper-bainite range—show clearly that the bainite (ferrite) needles are surrounded by residual austenite. It is seen from X-ray photographs that this austenite is carbon-enriched. Similar investigations have been described by Rose and Peter.[2]

The more difficult formation of bainite, which has been attributed to the effect of the carbide-forming alloying elements on the diffusibility of the carbon, certainly requires some additional explanation, since even non-carbide-forming alloying elements can slow up the bainite formation.

So far, we have not been able to establish that a higher initial temperature reduces the incubation period of the bainite transformation, as was shown in the second paper by Dr. Cottrell and Dr. Ko. The programme for our investigations of transformations in steels, the results of which we are now bringing together in an " Atlas of Transformations of German Standard Steels", includes not only the isothermal transformation diagrams for ordinary hardening temperatures (averaging about 850° C. for constructional steels) but also those for higher temperatures (1050° C. for constructional steels). Whereas, at this higher temperature, the beginning of the pearlite transformation is shifted much farther along the time scale, the beginning of the bainite formation remains unaltered in time.

The results in the paper by Dr. Otte and Dr. Ko agree qualitatively with those obtained in the investigations of the effect of the cooling process on martensite formation, which we have carried out to obtain data for transformation diagrams for continuous cooling.

In a discussion[3] on the theoretical assumptions concerning the stabilization of austenite, Morgan and Ko reject the 'composition change theory' for one reason, among others, that investigations of bainite formation have so far been unable to offer any evidence that a 0·1% enrichment of carbon in the austenite is possible before the transformation. In other investigations,[1, 2, 4] we have repeatedly found, by determinations of the lattice constants, not only that the carbon in the austenite has increased during the transformation from 0·4% to 1·2%, but also that, even at the beginning of the transformation, there is some austenite present, the initial carbon content of which has been increased by far more than 0·1%.

It is perhaps possible that the hypothesis of the formation of 'Cottrell atmospheres' around dislocations explains the stabilization below M_s, whereas in the range between 400° and 300° C. the predominating process is the change in concentration.

Dr. **T. Ko** (Birmingham University) : Mr. Bish and Professor O'Neill refer to the results given by Rostoker, who claimed that the Meyer indices for martensitic steels, using a diamond pyramid indentor, were greater than 2·0. Dr. Otte has carefully repeated Rostoker's experiments, using the same specimens, and obtained a Meyer index of 2·0 for all the specimens, as expected from the geometry of the indentations.

Dr. Otte also obtained the following results for 5% Ni steels quenched from 1100° C. (all the indentations were made at room temperature, using tungsten-carbide ball indentors) :

Carbon, %	Retained Austenite, vol.-%	B.H.N. $\left(\frac{L}{D^2} = 30\right)$	Meyer Index
1·0	25	425	2·49 ± 0·05
	About 3	640	2·43 ± 0·05
1·5	100	200	2·40 ± 0·05
	18	550	2·47 ± 0·05

Dr. **M. L. Becker** (British Iron and Steel Research Association) : I should like to ask Dr. Ko whether, if the austenite had a high carbon content—say, up to 1·8%—the first precipitate in the lower-bainite region would still be ferrite. It seems to me that, with all the carbon present in that austenite, even if ferrite were the first precipitate, the changeover to carbide would be almost instantaneous.

Mr. Bish and Professor O'Neill have devised a very interesting apparatus, and I hope that, if it still exists, as implied, it will be possible for some further use to be made of it. In Fig. 1 of their paper a diagram is given of the specimen used. I think it is a very neat device, but I should have thought that, if the high spots were pressed down to the level of the main part of the specimen, there would be so much side thrust that the specimen in those regions where there is supposed to be no deformation would nevertheless show deformation. The authors claim that the deformed and partly transformed austenite gives the highest hardness after final cooling. On looking at their micrographs, it seems to me that some minute cracks or something of that nature might have been introduced during deformation or transformation. I do not know why that should have occurred with austenite as soft as is claimed by the authors, but possibly I have misinterpreted the micrographs. I wonder whether the authors could give us their reasons for believing that the material had some exceptional properties. Would these include a higher fatigue strength or a greater ability to withstand cold deformation without fracture? If so, it would seem very unlikely that there could be micro-cracks present. Also, would the increased hardness obtained by deforming the austenite before transformation be due to the reduction of the amount of austenite stabilized on cooling to room temperature, which would presumably not be large in any case?

Dr. **J. Nutting** (Cambridge University) : In Fig. 7 of the appendix to the paper by Mr. Bish and Professor O'Neill, the hardness values for pearlitic and sorbitic steels are shown to vary with the percentage carbon content of the steel. Gensamer, Pearsall, Pellini and Low[5] have shown that in steel of a given carbon content there is a linear relationship between the logarithm of the mean free path of ferrite and the hardness, the smaller the mean free path the greater being the hardness. The hardness of the pearlitic and spheroidized steels could therefore have a wide range of values that could not be expressed by a simple linear relationship with carbon content.

If, however, we accept the hardness of cementite as 820 and that of ferrite as 100 and assume that there is a linear relationship between the volume fraction of carbide and hardness, it becomes possible to compare the values obtained with those found in practice. Mr. E. D. Hyam, who is carrying out research at Cambridge University on the tempering of steel, has found that after tempering a range of carbon steels for 100 hr. at 700° C. the hardness values obtained coincide almost exactly with those to be expected from the calculated carbide volume fraction. If the steels are tempered for more than 100 hr. the indications are that the hardness will fall further and linear relationship between volume fraction and hardness will no longer hold.

Using the relationship established by Gensamer *et al.*,[5] the volume fraction of carbide should not influence the hardness of the steel, the minimum value being always that of the ferrite until the volume fraction of the carbide becomes relatively large. This raises a general problem in measuring the hardness of aggregates. It would be useful to know how the hardness changes with variations in the relative sizes of the indentation and the particles of the dispersed phase.

Mr. **A. P. Miodownik** (Battersea College of Technology): Has Dr. Ko any information on the relationship between the habit plane for shear in bainite and that for shear in the subsequent martensite formation for a given steel? Also, in connection with his diffusion-controlled shear

reaction for bainite, does the initial plate of bainite form after some diffusion of carbon has occurred or does the diffusion of carbon occur after the first plate of bainite has formed?

In regard to micro-hardness testing, I have done a little experimental work on martensite of a plain carbon eutectoid composition. The results seem to indicate that the Meyer Index remains at $2{\cdot}00 \pm 0{\cdot}1$, even at loads below 30 g., although the accuracy of measurements at diameters $<3\mu$ is doubtful.

AUTHORS' REPLIES

Dr. **H. O'Neill** (in reply): We thank the speakers for the remarks that they have made.

We were interested to learn from Dr. Ko and Mr. Miodownik that their results for the diamond micro-pyramid test also show that the Meyer index is 2·0. Mr. Rostoker's results have always been rather a mystery, but their publication has now enabled the matter to be cleared up to some extent.

It is interesting that Mr. Jastrzebski's work on welding with austenitic rods has implications in connection with our paper. I cannot explain off-hand the points that he raised concerning the welds oil-quenched from 840° C., which showed a smaller difference in hardness values.

At the moment we are not doing any work on our machine, but Dr. Becker and Mr. Jastrzebski may like to know that we are looking for a very patient man who can be induced to do some more work upon it. We might then be able to study the effect of deformation on the M_s temperatures.

Only one of Dr. Otte's results for 5% Ni steels creates any difficulty for us—the 100% of retained austenite with an n value of 2·40. We think that figure should be more like 2·50; as Rostoker's figures have been improved, perhaps this figure also will change.

Regarding Dr. Nutting's contribution, the graph in the Appendix is chiefly assembled on macro-hardness tests, not micro results, and the low-carbon end of the diagram is intended to be a representative average of all the values that I have reviewed at different times. Over the eutectoid there tends to be a peak, and this effect also occurs in alloys like the eutectiferous copper–silver system. If there is a eutectoid or eutectic in the normally cooled alloys, the hardness is often somewhat above the supposed straight line of a conglomerate system, but that peak usually disappears during annealing and the general line is reached. My dotted line for the spheroidized steels is not meant to indicate more than that. Ordinary commercial steels in the ferritic and spheroidized forms give roughly these values, but when massive constituents and very small indentations are considered, the difficulty that Dr. Nutting has pointed out is evident. In this respect, results given in "The Hardness of Metals" (Table 77)[6] may interest Dr. Nutting.

Dr. **T. Ko** (in reply): On behalf of my colleagues, I thank all the contributors for the interest they have shown in our papers. I will first deal with questions on the papers concerned with stabilization of austenite.

The investigations on the effect of austenitizing temperature on the amount of retained austenite, shown in Fig. 4 in Otte and Ko's paper, were made to examine whether or not Harris and Cohen's finding,[7] that increasing austenitizing temperature has an important effect on the amount of austenite retained in a Ni steel, has any fundamental significance as claimed by Cohen.[8] We were therefore careful to produce an austenite free from graphite, although graphitization can take place very easily during annealing below Ac_m. Our results were negative, and we are in full agreement with the Russian workers' interpretation[9] of the results obtained by Cohen and his co-workers.

The absence of a residual effect of stabilization at — 79° C. in the carburized Krupp steel after stabilization at room temperature was, as stated in the paper, due to the gradual removal of the stabilization effect after the martensite transformation had resumed. I am pleased that Dr. Samuel's explanation of this recovery effect agrees with the suggestion we have already put forward.[3]

Regarding Dr. Samuel's question about the relationship between stabilization of austenite and bainite nucleation, Professor Wever and Dr. Rose have suggested that stabilization above M_s in the range 300–400° C. is probably due to carbon enrichment in the austenite during bainite nucleation.*

There is no doubt that the formation of bainite and any accompanying diffusion of carbon into austenite will cause a phenomenon similar to stabilization. The depression of M_s due to the formation of bainite is probably caused by (i) any carbon enrichment in the austenite and (ii) the plastic deformation associated with the formation of bainite, which increases the resistance to the growth of martensite, an explanation similar to the suggestion accounting for the athermal nature of the martensitic transformation.[3, 11] It seems to me, however, that carbon enrichment in austenite is not the only cause of stabilization above M_s, for the following reasons:

(i) Stabilization can be observed in some steels but not in others.[3, 12] There is no evidence that this difference also exists in bainite transformation in these steels

(ii) When stabilization occurs above M_s, it takes place only below a certain temperature, which lies below the upper temperature limit of bainite formation

(iii) Although carbon enrichment in austenite has been observed at the early stages of bainite transformation, it is unlikely that the carbon concentration can be uniformly increased so as to suppress completely the nucleation of martensite, and to depress M_s as observed by us[3] and by others[10, 13]

(iv) The degree of stabilization in terms of temperature lag θ in a Cr steel (En 31) has been shown[10] to increase with time to a maximum, decrease to a minimum, and then increase abruptly when bainite transformation sets in. A complex mechanism must be involved in the stabilization of austenite.

In connection with the papers on bainite Dr. Samuel referred to the ridges near the grain boundaries shown in our photographs of surface structure. This effect is often observed in thermal etching of many other metals and alloys, and is not connected with transformation.

In regard to the accelerating effect of high austenitizing temperature on bainite transformation in Ni–Cr–Mo steels, we are not completely satisfied with the hypothesis we put forward, although it is possible that the precipitation of sulphide particles may vary with the austenite composition. The reasons why we doubt that the homogenization of carbide-forming elements was contributing to the accelerating effect are: (i) homogenization of alloying elements usually results in an increase in the incubation period; (ii) we did not find such an effect in Cr or Mo steels, and (iii) the effect can be completely removed by re-austenitizing and partly removed by annealing at lower temperature in the austenite range (Fig. 4 in Cottrell and Ko's paper).

Mr. Mayer referred to the effect of holding in the upper-bainite range on the formation of lower bainite. The result is very interesting. Dr. Cottrell and I have

* Professor Okamoto and Mr. Odaka[10] have also postulated that stabilization in a chromium steel (En 31) may be due to the formation of Preston–Guinier zone-like clusters during stabilization treatment. This paper was unknown to the present authors when their papers were prepared.

also studied the effect of holding an En 25 Ni–Cr–Mo steel in the temperature range in which austenite is stable on the subsequent bainite transformation below these holding temperatures. In this steel, austenite is very stable at about 550° C. with an incubation period for pearlite of not less than three days. When the steel was quenched to this temperature and held for periods between 15 min. and 16 hr., the subsequent isothermal transformations at 375° and 400° C. (near the 50% transformation) were increased by 40 and 20% respectively. The effect of ageing at 550° C. on transformation above 435° C. was almost negligible. The effect of holding above and below 550° C. was also smaller than holding at 550° C. Much work remains to be done on the effect of step quenching.

Mr. Miodownik referred to the habit planes of bainite and martensite. Mr. Mayer has mentioned that in En 23, a 0·3% C steel, the upper and lower bainites seem to have the same habit planes. On the other hand, Smith and Mehl[14] have observed that in a eutectoid steel the habit planes of the bainite change from those of pre-eutectoid ferrite at high temperatures towards that of martensite at lower temperatures. This is consistent with my view that the strain or the distribution of carbon in bainite is one of the factors that determine its habit planes.

Dr. Becker asked whether in high-carbon steels we should get bainite first. If the term ' bainite ' is used to indicate the diffusion-controlled coherent transformation product in the intermediate range, then in high-carbon steels bainite is normally preceded by cementite at high temperatures. At low temperatures, bainite transformation in a high-carbon steel is not different from that in a eutectoid steel, except in morphology.

Dr. Samuel has referred to the factors controlling the growth of bainite and stated that the activation energy for bainite growth estimated from our photographs of bainite growth taken at 275° C. is 36,000 cal./mole, which corresponds to that of carbon diffusion in austenite. There are too many assumptions involved in estimating the activation energy of a process from rate measurements made at one temperature. Furthermore, if the mechanism of bainite formation we suggested is essentially correct, the rate of growth will depend on at least four factors: the rate of diffusion of carbon in austenite and in bainite, and the rate of precipitation of ε-carbide and cementite in austenite and in bainite, all in the presence of various degrees of elastic and plastic strains. I do not think, therefore, that activation-energy measurement will give much indication as to the mechanism of bainite formation. Any activation-energy measurement can be properly interpreted only if the mechanism is known.

Dr. Samuel has questioned whether supersaturated ferrite can be strain-free. His remark probably refers to Zener's attempt[15] in respect of the thermodynamics of bainite transformation, in which he deliberately neglected the strain energy due to the assumed supersaturation. It does not apply to the present theory of bainite formation, in which we suggest that the upper bainite grows in the form of α-iron relatively free from carbon and not as supersaturated ferrite.

We are very pleased that our suggestion that bainite can grow by removing the carbon from bainite into the austenite has received experimental confirmation from Professor Wever and his co-workers, who have contributed much towards the understanding of the transformation. We have also observed[16] that carbon-free α-iron can be precipitated at high temperatures by the bainite mechanism in hypo-eutectoid steels. Professor Wever's observation[1] that the carbon in the austenite between α-iron plates finally precipitates as carbide is also consistent with our view on the mechanism of formation of feathery upper bainite.[16]

The other part of our hypothesis that the growth of lower bainite takes place mainly by the reduction of carbon through precipitation of carbide has led to the interesting suggestion that martensite should grow during tempering, provided that the austenite–martensite interface remains coherent after the formation of martensite plate has ceased. We have been able to show[17] that high-carbon martensite, which tempers rapidly, can grow further during tempering by the martensite and bainite mechanisms at high temperatures or by the martensite mechanism at low temperatures. It can be shown, by studying the surface relief during tempering after anodically colouring the austenite, that the growth takes place at the expense of the austenite next to the original martensite plate. With this further evidence, we believe that the theory proposed is substantially correct.

We fully agree with Professor Wever and Dr. Rose that much work remains to be done, especially on the effect of alloying elements on the bainite transformation. The ability of non-carbide-forming alloying elements, such as Ni, to slow down the bainite formation is probably the result of their effect on nucleation, the free-energy change at a given temperature being reduced by the presence of these austenite-stabilizing elements. The effect of carbide-forming elements, on the other hand, is due to their influence on the mobility of carbon in α-iron and in austenite. A quantitative study of the effect of alloying elements on the rate of nucleation and the rate of growth of bainite will be needed to confirm the validity of these suggestions.

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Joint Discussion on the Papers—

SPEED-DEPENDENT VARIABLES IN COLD STRIP ROLLING*

By R. B. Sims and D. F. Arthur

PERFORMANCE OF HYDRODYNAMICALLY LUBRICATED ROLL NECK BEARINGS†

By R. B. Sims

CONTROL OF STRIP THICKNESS IN COLD ROLLING BY VARYING THE APPLIED TENSIONS‡

By R. B. Sims, J. A. Place, and P. R. A. Briggs

WORKS TRIAL OF THE 'T' METHOD OF AUTOMATIC GAUGE CONTROL§

By R. B. Sims, J. A. Place, and P. R. A. Briggs

Mr. **R. B. Sims** (Davy and United Engineering Co., Ltd., formerly British Iron and Steel Research Association) presented all four papers.

Mr. **R. Cook** (Steel Company of Wales, Ltd.): These papers are full of interest, since gauge control is of great importance and off-gauge is a product resulting in waste of money and material. If the ultimate answer to the problem of obtaining correct gauge can be found in automatic control, the latter should be followed to its ultimate conclusion.

One very important feature of a tinplate mill, *i.e.*, the screwdown, has been largely nullified under this control. In tinplate production it is essential to have a flat and uniform strip to process, and the variations that are encountered make it necessary to have the use of the screws at all times. We invariably correct a loose or wavy edge during the running of a coil by operating the inside or outside screw. Mr. Sims did not make it clear whether the screws could be used in this way to correct the shape.

In the method outlined by the authors, the experiments gave an accuracy of approximately $\pm$ 0·0015 in., which may well be suitable for sheet tolerances but would be unsuitable for tinplate manufacture; so that, until tinplate rollers are given evidence of the ability of this control to maintain gauge to a finer tolerance, in the region of $\pm$ 0·0004 in., they will not be convinced that its application would be beneficial to them.

Of the factors that may have an ultimate bearing on the production of flat uniform material, consider first the varying thickness of the incoming band. The paper on automatic gauge control does not indicate clearly how this control would work between Stands 1 and 2. Normally, if the band is heavy coming into No. 1 mill the operator would come down on No. 1 screws, or, if the load was already high on that mill, he would reduce the speed on No. 1 mill, so that only sufficient material would be thrown into No. 2 mill for the latter to be able to cope with it at its correct speed, so that the gauge could be maintained to No. 5 mill. With the automatic control on No. 2 mill, the heavy gauge into No. 2 would be taken out of that mill by an increase in speed on No. 3, and there would surely then be a tendency to throw slack between No. 3 and No. 4.

Under normal rolling conditions the rolling lubricant would be expected to remain constant, but sometimes palm-oil failures occur, and the tension between the stands where the palm oil is applied is therefore increased. This is usually adjusted by operating the screws, but it is difficult to see how the automatic control would effectively deal with these conditions; it seems probable that the strip would be submitted to excessive tension and would break.

It is not clear from the authors' experiments how they would deal with steel of varying hardness, which brings about conditions that require initially the easing of the screws on No. 1 mill so as not to work-harden the strip before reduction in the following mills. If the No. 1 screws are not eased—and we have done this in experiments on our own mill—there are cases where the gauge cannot be maintained because the strip is so hard, and bad shape results. In other words, the increase in tension due to the varying hardness of the steel coming into the rolls would give a false signal to the following mill, and would cause strip breakage.

To deal with bad shape we require not only the application of the roll coolant but also the use of the screws, and it would appear that the control suggested by the authors would not allow this. I am therefore at a loss to understand how the ultimate shape and gauge can be obtained merely by the control suggested.

Mr. **Sims**: The control is already working at $\pm$ 0·0015 in. Mr. Cook's figure was 0·0004 in.

Mr. **P. E. Peck** (British Thomson-Houston Co., Ltd.): On p. 358 of the fourth paper, the authors state that the speed effect of the mill at Shotton is very large. Can they give any figures for this? What are the main contributory factors, and which of these can be reduced by the gauge control?

On pp. 357 and 358, reference is made to loss of sensitivity at low speed when the control is through the field of a motor, and on p. 358 the inference seems to be that this is due to the current falling almost to zero during retardation. In fact, the loss of sensitivity at low speeds has two aspects.

The control depends on the change of motor e.m.f. brought about by changing its field current. There are two aspects of this: (i) When running at constant voltage, the change of e.m.f. for a given change of field current depends on the slope of the motor-speed/field-current curve, and this demands a much greater change of

* *J. Iron Steel Inst.*, 1952, vol. 172, Nov., pp. 285–295.
† *Ibid.*, 1952, vol. 172, Dec., pp. 415–418.
‡ *Ibid.*, 1953, vol. 173, Apr., pp. 343–354.
§ *Ibid.*, 1953, vol. 173, Apr., pp. 354–360.

current for a given e.m.f. change at full field than at weak field. (ii) For any field setting, the e.m.f. for a given field current depends on the r.p.m. of the motor. If the speed is reduced by voltage control (as when retarding the mill), the change of e.m.f. due to a given change of field current is proportionally reduced. It is this effect which is responsible for the loss of sensitivity when bringing the mill to rest.

Mr. **M. F. Dowding** (Davy and United Engineering Co., Ltd.): The authors are to be congratulated on reaching near success in their first industrial application of automatic gauge control, and in applying the 'T' method to the large tandem mill of John Summers and Sons they have undoubtedly succeeded in proving that the system works in principle on this application.

It is now generally known that the development of this system from laboratory trials to industrial applications is largely being undertaken by a joint team formed between my Company and B.I.S.R.A., and it may be of interest to give details of the suggested programme.

We are starting with the development to the manufacturing stage of loadmeters and other instruments such as tensiometers, including the gaugemeter referred to by Mr. Sims. Once these are established as useful, sturdy, and practical mill instruments, automatic gauge control in its various forms (on which research and laboratory trials will proceed simultaneously) will be ready for general application. It is hoped that the manufacture of the instruments and gaugemeter will be in progress in the early part of 1954. Automatic gauge control, in the form shown experimentally to be most suitable for the various applications in which people are interested, would start about six months later.

We are indebted at this stage to Richard Thomas and Baldwins at Ebbw Vale, who have offered their hot mill for gaugemeter trials in July of this year, and to I.C.I. at Witton, who have offered for this summer a small single-stand cold brass mill which they are re-motoring.

Mr. **W. Spence** (British Thomson-Houston Co., Ltd.): The desirability of minimizing the percentage of off-gauge strip rolled in continuous strip mills cannot be questioned. The economic aspect of the problem, however, must also be considered. The tension method of gauge control, although demonstrated successfully on a 1500-ft./min. tandem mill rolling sheet gauges, is by no means free from disadvantages. (The disadvantage of variable sensitivity with speed on the trial installation described by the authors is, of course, readily overcome on mills fitted with armature-circuit boosters or individual generators.) Two main factors, however, put the tension method at a disadvantage when its universal application is considered.

First, on a modern high-speed mill rolling thin-gauge material the potential change of gauge due to the speed effect can be as high as 30–40%, most of which develops in the later stands. To counteract such an increase of gauge by increasing the tension between, say, the last two stands would call for an additional tension of the same order as the normal running inter-stand tension. Since the latter is usually quite close to the yield-point stress of the material, it follows that the strip would break in the attempt to hold gauge by tension, when coming down to threading speed. The authors seem to have recognized this possibility and fitted their equipment with an overriding tension limit, but I wonder whether this does not virtually restrict the action of the automatic gauge control on a tinplate mill to the maintenance of gauge while running, a function which presents little difficulty to an experienced crew of operators.

My second point is that, since the speed effect is most evident in the later stands, gauge control by tension should properly follow the final stand. High tensions are undesirable between the mill and the wind-up reel, so that to use gauge control by tension after the last stand it appears to be necessary to interpose a pair of puller rolls between this stand and the reel, together with a drive motor of relatively large rating.

What is really required is automatic gauge control by roll pressure on the hot mill, a problem on which the authors are also working. If the incoming band at the cold mill is of correct gauge from start to finish, I suggest that the remaining need for automatic control of gauge of cold-rolled strip with varying speed can be adequately met by existing control methods applied to the stand drives. These can equally well be arranged to bring about an increase in inter-stand tension up to the safe limit as speed is reduced.

Speculation about future developments in cold strip rolling leads me to believe that what is now essentially a batch process with intervals between coils will eventually become a truly continuous rolling process with a looping pit ahead of the first stand, preceded in turn by a welder and pay-off reel. The delivery end of the mill will probably have two reels with automatic shear and belt-wrappers for non-stop change-over when one coil is full size. Slowing down such a mill may still be necessary to pass welds and change reels, but it should not be necessary to slow down beyond a speed below which most of the change of gauge due to the speed effect seems to take place. The percentage of off-gauge material from this type of mill should be very small indeed.

Mr. **K. H. Slack** (British Iron and Steel Research Association): For the past two years I have been associated with Mr. Sims on the setting method of gauge control which he mentioned briefly, and I would like to compare the merits of this form with the tension method.

The tension method of gauge control, as pointed out in these papers, may be applied to only a few existing single-stand mills, since quite large tensions are required to cause an appreciable change in strip thickness. There are not many mills equipped with coilers capable of applying high tensions without damage, nor yet with the reel motor powers required for this duty.

The control may be carried out on a tandem mill as described in the second paper, and here there is the difficulty that, in using inter-stand tension when all stands are heavily loaded, the correction is made in the penultimate stand. Hence, although the strip is on gauge in this stand, variations will reappear due to the effect of tension on the last stand, although to a lesser extent.

It will be realized that it is necessary, in this control system, to balance the servo while rolling the first coil of a batch at slow speed, and as soon as the strip is at the required thickness the control is put into operation. If the production is in small batches of differing gauges, however, the controller must be reset for every gauge. This setting is somewhat inaccurate, since the strip is not measured in the rolls but at some distance away, where the micrometer makes contact with the strip. A lag is therefore introduced which could be troublesome. In normal production today, the rolls must be adjusted until the strip is on gauge, and because the automatic balancing of the servo takes less than 1 sec. the 'T' method does not delay production seriously. The 'S' method, however, is far superior. The control consists simply of three indicating dials on which the required gauge is set. The method measures strip thickness at the roll gap and does not rely on a contact micrometer. If the rolled strip does not correspond in thickness to the required value, the rolls are repositioned automatically

by the servo. Production is therefore greatly speeded up and mill operation simplified.

The other advantage of the setting method over the tension method is that it gives full gauge control within 3–6 in. from the beginning of the coil and to within 1 in. from the end of the coil, whereas in the tension method a length of strip at least the distance between the rolls and the tensioning device is off gauge, as in present practice, and in addition there is the off-gauge strip produced before the contact micrometer indicates the correct gauge on the first coil of a batch.

The authors have mentioned that the variation in tension did not seriously affect shape. I would point out that in the 'S' method the tension may be held constant to any desired value, if necessary, by an independent controller, and the best possible shape is therefore obtained.

CORRESPONDENCE

Dr. **N. H. Polakowski** (University College, Swansea) wrote: The authors have emphasized how little was done or known before their results were published, but I should like to point out that:

(i) I showed a few years ago in this *Journal*[1] and elsewhere[2] that variations of friction in the roll gap can adequately account for the effect of rolling speed on strip thickness. As far as I am aware, the essence of my theory was never disproved, and it is now commonly accepted, even if without reference to the source of inspiration.[3]

(ii) A reference to experiments on the dependence of forward slip on rolling speed was made by Underwood,[4] also in this *Journal*.

(iii) The variations of oil-film thickness in hydrodynamically lubricated bearings have been measured previously by Stoltz and Brinks[5] over a wider range of mill speeds than that used in the tests described in the second paper.

(iv) An automatic gauge controller was installed and tried on a 5-stand tinplate mill more than 13 years ago.[6] This embodied two basic features used also in the apparatus invented by the present authors. In each case the gauge was kept constant by automatically altering the tension between the last two stands, and tension-limiting circuits were provided in both designs.

It is clear that the present authors have freely drawn on others' work and ideas, and one can only wonder at all their direct or indirect 'priority claims,' supported by references to their own publications in the period 1951–53.

It would be interesting to know the limits within which the tension varied in some of the experiments reported; *e.g.*, in Fig. 15 of the third paper, passes 2 and 3, and also around *A*, *B*, *C*, and *D* in Fig. 8 of the fourth paper. Knowledge of these figures, both in tons per sq. in. and in terms of the ratio specific-tension/U.T.S., is essential to enable one to assess the possible risk of strip breakage. One break of the strip caused by excessive tension may easily offset any off-gauge savings, by resulting in roll wreckage and loss of production.

Finally, it appears that, in steady rolling, limits of ± 0·001 in. on 0·020 in. strip can be maintained without any special control refinements (*see*, for example, Fig. 1 in Mohler's paper[6]).

Dr. **C. S. Ball** (Department of Industrial Metallurgy, Birmingham University) wrote: I have read the papers by Mr. Sims and his co-authors with great interest. It is to be hoped that the notable advances in our knowledge of the cold-rolling process which have been brought about by these detailed investigations will be put to good use, and in particular that the tension method of strip thickness control will receive, from the cold-rolling industry in general, the serious consideration that it merits. In view, therefore, of the importance and conclusive nature of the authors' final observations, I should like to raise a few points, some of which have apparently been dismissed without sufficient consideration.

In investigating the variables that affect the exit thickness of cold-rolled strip, considerable use has been made of a relationship claimed to exist between the mill load and exit thickness when rolling strip with a constant roll setting; namely,

$$F = M\,(h - S_0),$$

where M is defined as the effective elastic coefficient of the mill concerned. Similarly, the statements are made that the distortion at any point in the mill will be proportional to the applied load (p. 344 of the third paper), and that this relationship is unique so that if the mill load and roll setting are constant the strip will be rolled to a uniform gauge, regardless of changes in strip width, hardness, or frictional conditions (p. 294 of the first paper).

As is pointed out in the papers, the elastic deformation of the mill as a whole under load may be separated into the deformation of the mill housings, screws, etc., and the deformation of the rolls, and, using the same notation,

$$M = \frac{M_H M_R}{(M_H + M_R)}.$$

The numerical value of M_H for any mill will depend on the design of the housings and the cross-sectional area of the frame, screws, and associated members, and it will not be affected by the dimensions or characteristics of the rolled strip. The assumption of an effective elastic coefficient governing the deformation of the rolls is, on the other hand, an approximation, since the elastic deformation of the rolls in any one pass is a function of the roll load per unit strip width, the length of the arc of contact, and the roll radius, together with the appropriate elastic constants for the material of the rolls.[7] Since M_R depends on the change in elastic roll deformation with variation in mill load, the numerical value measured by experiment will depend on the manner in which varying mill loads are obtained. If, for example, the effective elastic coefficient of the mill is determined by rolling strips of a soft metal such as aluminium, the strips being of constant width and differing initial thicknesses, then unless the ratio h/D is very small the elastic deformation of the rolls will, at all loads, be comparatively small and the change in the roll deformation between low and high loads will also be small, and so the effective elastic coefficient of the rolls (and of the mill) will be large. In the opposite case, *e.g.*, rolling narrow steel strip of constant width and differing initial thickness, both the total deformation and the change in deformation of the rolls will be considerably greater, and the value of M_R (and M) will be relatively small. If the variation in roll load is obtained by altering the strip width, the value of M_R obtained will again be high, since the elastic deformation of the rolls is primarily dependent on the roll load per unit width of rolled strip.[7]

I have recently been investigating these effects on the 14 in. × 18 in. 2-high strip mill in this Department, and I hope to publish a note on the results shortly. In brief, these bear out the above arguments in that when rolling annealed aluminium the effective, measured, elastic coefficient of the rolls was 140,300 tons/in. deformation of combined rolls, and when rolling steel the effective coefficient was 14,540 tons/in. The values of M obtained were respectively 3589 tons/in. and 2961 tons/in.

When rolls without camber are pressed together, it is obvious that the width of the rolls fixes one dimension of the rectangle of contact, and the other, the shorter side, is a function of the roll load, roll radius, and elastic constants;[8] hence, the relationship between roll load and screw setting is unique and may, with sufficient accuracy, be regarded as rectilinear. It would be expected, therefore, that an agreement between the F/h curve determined by rolling strips and the F/h curve determined by pressing the rolls together would occur only if the experimental conditions were such that the deformation of the rolls was similar in each case, and this agreement may be regarded as being coincidental. The correspondence between the two curves in the authors' case is assisted by a small roll diameter and by the fact that the curves have been transposed to a common reference point, so comparing the change in roll deformation with variation in load, rather than the total amount of deformation. In this connection, I should be interested to know whether or not the rolls on the 10-in. experimental mill were cambered, since this would also affect the effective elastic coefficient of the rolls.

In view of these arguments, the statements concerning a unique relationship between mill load and rolled strip thickness cannot be said to be true. As a matter of interest, in my experiments mentioned above, for a roll load of 120 tons and a roll setting of 0·030 in., the exit strip thickness was 0·0477 in. when rolling aluminium, 0·052 in. when rolling copper, and 0·057 in. when rolling medium-carbon steel. The ratio of the elastic deformation of the rolls to that of the housings, screws, etc., was respectively 0·02, 0·11, and 0·22.

It would seem, therefore, bearing these arguments in mind, that in the discussion of possible speed-dependent variables the evidence advanced in Fig. 2, p. 288 of the first paper, as it stands, is insufficient to convince the reader that the theory regarding changes in elastic modulus is incorrect, although this in no way detracts from the final conclusions in respect of the part played by the coefficient of friction. In view of the experimental conditions, the use of a constant effective coefficient of elasticity of the mill in the experiments with fluid film bearings is justified, and Mr. Sims may be interested to know that we have also observed very similar 'hysteresis' effects to those shown in Fig. 3 of the second paper.

In regard to the important development of the tension method of strip thickness control, I think it is possible that a distinction may be drawn between the accuracy of the method when used to control variations in gauge arising from variations in speed of rolling, ingoing thickness, etc., and the accuracy when used to hold the exit thickness constant when the rolled strip width varies. My experiments mentioned above indicate that Hitchcock's equation relating to the elastic deformation of the roll and strip dimensions gives a reasonably accurate estimate of the roll deformation. This equation may be written, using the same notation, in the form

$$Z_0 = K\frac{F}{B}\left\{\log_e\frac{2R}{\sqrt{R'\delta}} - 0{\cdot}306\right\},$$

where Z_0 is the radial elastic deformation of the roll at the plane of exit and K is a constant for any one pair of rolls.

Hence, if the ingoing width remains constant, this equation suggests that the deformation of the rolls, depending only on the logarithmic term, will remain substantially constant. If, however, the rolled strip width varies while the roll load remains constant, the elastic deformation of the rolls may vary appreciably. For example, a medium-carbon steel strip of width 3·125 in. given a reduction of 27·4% on the mill in this Department gave rise to a roll load of 112 tons. Assuming that Hitchcock's equations are accurate, that the roll load remained constant, and that the new value of δ satisfied both the above equation and that relating the rolling conditions to R', then a reduction of 10% in rolled strip width would cause a combined change of $0{\cdot}6 \times 10^{-3}$ in. in the radial deformation of the rolls. It is not possible at the moment to say that this figure is exact, nor need such variations in width occur in practice, but it suggests that the tension method may not control variations in gauge arising from this cause as accurately as it does other variables. It would be interesting to know if the authors have any experimental evidence which would throw light on this question.

The authors, in these papers, have not indicated what importance they now attach to the absolute value of the effective elastic coefficient of the mill and, in particular, to the value of M_H. Other things being equal, the greater the value of M_H the smaller the value of the change in exit thickness for a given minimum sensitivity of the loadmeters. Do the authors consider that the accuracy and stability of the loadmeters is such that the rigidity of the mill is unimportant and the factors limiting the control obtained lie elsewhere ?

Finally, I should be pleased to know if the authors have any information concerning the change in roll setting brought about by temperature changes. Considerable importance is attached to cooling systems in cold rolling in industry, and it would be interesting to know whether, in their extensive investigations, the authors have ever been able to estimate approximately the importance of this complex variable.

AUTHORS' REPLY

Mr. **R. B. Sims** (in reply): In their paper on the principles of automatic gauge control, Hessenberg and Sims[9] suggested from their analysis two possible methods of controlling the thickness of rolled strip. It is perhaps unfortunate that in presenting the above four papers we have discussed one method only, the tension method (which we abbreviate to AGC 'T'), and have neglected to present at the same time the roll-setting method (AGC 'S') in its true perspective. The experiments with AGC 'T' were carried out on the 4-stand tandem of Messrs. John Summers and Sons Ltd., at Shotton, because it was the only mill available to us in October, 1951, when the trial was begun. It was not entirely suitable for the work, and AGC 'S' would have been fitted in preference had it been sufficiently developed. The Shotton experiments were carried out to demonstrate the possibility of control on large mills at high speeds. It was not intended that this should be a final recommendation to industry on automatic control for tandem mills.

Many of the practical difficulties in operating a high-speed tandem mill which were raised by Mr. Cook are resolved by the use of AGC 'S.' One important point to be remembered when discussing the application of any form of AGC to a tinplate tandem mill is the phenomenon of limiting reduction. It is well known to tinplate rollers that at any given mill speed the strip cannot be rolled below a certain gauge, whatever load is applied to the rolls. Thus at normal thread speeds the limiting gauge is about 0·018 in., and it is not until the mill is accelerated above about 600–1000 ft./min. that tinplate gauges may be rolled. This effect, which has been discussed fully elsewhere,[10] takes place regardless of the load or tension applied to the strip, and cannot be controlled by any method dependent on the application of tension or movement of the rolls. It is due to the high frictional forces at the roll gap at low speeds, and at present tinplate cannot be rolled until the coefficient of friction falls to

below about 0·04–0·03, owing to the speed effect, as demonstrated in the paper by Sims and Arthur.

Automatic gauge control can be applied successfully at any speed to the first three stands, since the limiting reduction is far greater than that taken in normal production with a tinplate mill; AGC 'S' would be the method preferred, and a close control of gauge could be achieved out of each stand. But AGC can be obtained out of stand 5 (again preferably by AGC 'S') only when the coefficient of rolling friction is sufficiently low, either when the mill speed has been raised sufficiently or when a rolling lubricant is used giving the required low friction.

With AGC 'S' the operator has full control of his screws. Should he wish to screw up or down during a pass, he would alter the gauge setting at which his controller is working. He has with AGC 'S,' therefore, the same liberty that he has at present to sacrifice gauge for shape, and after each adjustment the controller would continue to maintain gauge at whatever thickness the roller sets on the controls.

Experiments carried out so far indicate that the tension method of automatic gauge control will produce strip to closer tolerances than the 'S' methods of control. Disregarding roll eccentricity (for which there is at present no remedy except greater care in roll grinding), there has been no difficulty in achieving a tolerance of better than ± 0·0002 in. with strip possessing large variations in hardness, ingoing thickness, and speed effect. The 'S' method of control applied to an experimental mill with hydraulic loading of the screws[11] has reached an accuracy of ± 0·0005 in., and the variant which uses the mill screws to adjust the position of the rolls has been used with an accuracy of about ± 0·0007 in. on strip with relatively slow variation in thickness, although the error may be greater when the gauge changes quickly, and depends on the rate at which the mill screws may be adjusted and on the speed of the strip.

Thus, AGC 'T' and AGC 'S' have well-defined fields of application which do not greatly overlap. The AGC 'T' method will be applied to small or medium single-stand mills rolling a high-quality product to very close tolerances in gauge. The 'S' methods of control will be applied to all mills, including hot tandem mills, where the tolerances produced by these systems are adequate and the emphasis is on production and ease in handling the mill. The screw-operated method, AGC 'SD,' may be used on the majority of existing plant; the more precise hydraulic system AGC 'SH' requires a radically new design of mill and is, perhaps, the method of the future.

We are not at liberty to discuss with Mr. Peck the details of the speed effect in the Shotton mill, but we would say that it is due partly to the true frictional speed effect in all four stands, the variations in tension due to the mill drive, and changes in the oil-film bearings. It may be corrected completely, as demonstrated in the paper. The changes in sensitivity in the controller arise from both the motor characteristics given by Mr. Peck. It is agreed, however, that the rapid changes found on full deceleration are due to the second cause he mentions.

The 30–40% speed effect mentioned by Mr. Spence occurs when rolling from low speeds, and a much greater speed effect occurs when rolling to galvanizing-sheet or tinplate gauges, owing to the phenomenon of limiting reduction as described above. Mr. Spence will observe that the entire speed effect was controlled at Shotton with tensions which did not exceed half the yield stress of the material. The speed effect in cold rolling cannot be prevented, even by perfect gauge control at the hot mill.

The constancy of the elastic coefficients of the mill, M, and of the rolls, M_R, has already been discussed.[9] There does not seem to be an analysis of the problem of the elastic deformation of a mill roll. The question of whether it depended on the width of the strip was examined early in the research on AGC, when coils of 1½-in. wide stainless steel, 3½-in. wide mild steel, and 3-in. wide high-conductivity copper were rolled in the 10 in. × 10 in. experimental mill and M_R was measured directly. Over 100 results were taken, and the value obtained for M_R for all materials was 4050 ± 20 tons/in. The value of the effective mill modulus M has been measured from a large number of results, both with the rolls pressed together and when rolling strips of widely differing widths and thicknesses of some twenty different metals. The technique of superposing these values on a single graph is not considered to affect the value of M obtained, for it is the slope of the line which is required, and the technique is a standard statistical one.

It has been found from experience that a very large number of readings are required to establish true values of M and M_R, since considerable errors may arise from roll eccentricity, instrument error, and variations in gauge. Apparent variations in the elastic coefficient of the mill across the strip have been observed when rolling with a light reduction on narrow strip of high yield strength, and these are due to local distortion of the rolls in the arc of contact, analogous to the deformation that increases their radii of curvature locally near the roll gap. The effect is not large and does not alter the statement that the value of M is effectively constant in any single pass in a mill.

The roll camber does not influence the value of M, since this includes the effect of roll bending. In the experimental mill the rolls are ground without camber, but those at Shotton were cambered in grinding and additional camber was induced by differential cooling.

With AGC, M is of value only in establishing circuit constants, and its absolute value is not important to closer than about ± 5%. The loadmeters used in the circuits have been found to be reliable and stable at all levels demanded of them to date.

The problem of dimensional changes in mill rolls due to temperature changes is not known and is the subject of current research. No definite evidence is yet available.

It would be of interest to know how Dr. Ball was able to maintain a constant roll setting and a constant load on his mill when rolling material of such widely differing characteristics. The variations in gauge he observed—between 0·0477 in. and 0·057 in.—are far greater than anything found in the present investigations, and can be discussed only when the full experimental details are published.

We would draw Dr. Polakowski's attention to the fact that a detailed and adequate review of literature on the speed effect was given by Ford[12] in 1947, and the possibility of friction being the speed-dependent variable was fully considered. As Professor Ford realized then, a wide speculation on the origin of the speed effect was of little value, and he attempted experiments to determine it directly. It was unfortunate that his experiments were unsuccessful in establishing friction as the prime cause, and we would emphasize that the work described in our paper on speed-dependent variables was an attempt to put on a firm experimental basis, for the first time, a prolonged discussion to which many authors, Dr. Polakowski included, had contributed without approaching nearer to a conclusion.

The work of Stoltz and Brinks to which reference was made in the second paper did not give reliable values of the changes in the thickness of the oil film in the bearings. The present experiments were intended to establish the order of magnitude of the change at mill speeds up to

1500 ft./min. It is considered that extrapolation to higher speeds may be made without gross error.

The history of automatic gauge control since 1920 has been described by Hessenberg and Sims,[9] and we have no doubt that it extends deeply into the recesses of the nineteenth century. As these two authors emphasized clearly, their original contribution to the technology was the use of the roll-force meter to control gauge, not tension (which had been used by Aluminiumwerke A.G. Rohrschach in 1923) or the repositioning of the rolls (which has been used by everybody else). The tension-limiting controls were intended only as an expedient to ensure the safe operation of the main controller. The method of gauge compensation mentioned by Dr. Polakowski is presumably the ' taper tension ' device, which was not an automatic closed-loop circuit controlled by the gauge error and presumably for that reason did not enjoy the wide popularity that would be certain for any *successful* and practical method of fully automatic control.

Details of the values of tension used in the AGC ' T ' experiments are not available, but Dr. Polakowski may like to know that the tension-limiting controls were set at about three-quarters of the yield stress or below in the experimental work carried out on the 10 in. × 10 in. mill.

Mr. Slack pointed out that, at Shotton, control was applied to the third stand, and further off-gauge could be expected from stand 4. As mentioned in the paper, this contingency was avoided by careful design, and the gauge measured out of stand 4 did not vary by more than ± 0·0005 in.

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Joint Discussion on the Papers—

TEMPER-BRITTLENESS: A CRITICAL REVIEW OF THE LITERATURE*

By B. C. Woodfine

SOME ASPECTS OF TEMPER-BRITTLENESS†

By B. C. Woodfine

TEMPER-BRITTLENESS IN HIGH-PURITY IRON-BASE ALLOYS‡

By A. Preece and R. D. Carter

EFFECT OF ARSENIC AND ANTIMONY ON TEMPER-BRITTLENESS§

By G. W. Austin, A. R. Entwisle, and G. C. Smith

Mr. **B. C. Woodfine** (Sheffield University), who presented his papers, pointed out that he had omitted to draw attention to some later papers by Jacquet,[1] Weill,[2] and Bückle.[3] Professor **A. Preece** (King's College, Newcastle-upon-Tyne) presented the third paper and Dr. **A. R. Entwisle** (Sheffield University) the fourth.

Dr. **N. P. Allen** (National Physical Laboratory): I agree with Mr. Woodfine in the great importance that he attaches to the paper by Jolivet and Vidal, but he does less than justice to the work of Greaves and Jones when he says that they did not realize that the temper-brittleness phenomenon was essentially a matter of the lowering of the transition temperature.

All the authors agree that the raising of the transition temperature in the impact test is essentially due to a lowering of the brittle strength of the metal, and two of them have confirmed this by means of low-temperature tests. All the authors agree that this is due to the appearance of a grain-boundary fracture. At the N.P.L. we have confirmed that these three things are associated with each other in other cases. In our work on pure iron with additions of nitrogen, oxygen, and phosphorus, a raising of the impact transition temperature has almost always been accompanied by a lowering of the stress at which a brittle fracture occurs at — 196° C., and very often by the appearance of an intercrystalline fracture.

That leads one to measure the brittle strengths of metals, particularly those of ordinary structural materials at ordinary temperatures. Experimentally, that involves finding some way of postponing plastic deformation until the rupture stress is reached, by some experimental

* *J. Iron Steel Inst.*, 1953, vol. 173, Mar., pp. 229–240.
† *Ibid.*, 1953, vol. 173, Mar., pp. 240–255.
‡ *Ibid.*, 1953, vol. 173, Apr., pp. 387–398.
§ *Ibid.*, 1953, vol. 173, Apr., pp. 376–386.

device that does not itself alter the rupture stress. From this point of view, the study of temper-brittleness resolves itself into listing the many factors which lower the brittle strength. The paper by Preece and Carter is particularly useful in drawing attention to the very dangerous nature of the combination of phosphorus with manganese or chromium; this has been suspected but has never been demonstrated so clearly before.

The demonstrations in regard to arsenic and antimony are equally valuable, but there are also many heat-treatment factors that are not fully realized. The solidification rate appears to affect the value of the brittle strength of the material in some unknown way. During the war failure of certain tank-armour castings was traced to temper-brittleness in castings of a composition that would have been quite free from temper-brittleness in forgings.

Another factor is that of the conditions of transformation of the steel. At the N.P.L. we are studying the impact transition temperatures as a function of the way in which the material transforms from austenite. Both the tensile strength of the materials when tested in the brittle condition at low temperatures and the impact transition temperature are affected by the precise manner of transformation.

The temper-brittleness phenomenon is a manifestation of the effects resulting from allowing the material to remain at temperatures of about 500° C. for various lengths of time. We were beginning to develop the view that the common factor is the opportunity for the segregation of impurities to take place in the course of the heat-treatment. But in some recent cases the material which is cooled most quickly, and therefore has presumably had the least opportunity for segregation of the impurities, has been the most brittle and has had inferior properties at low temperatures, and our tentative explanations have consequently been upset.

There are two opinions about the explanation of temper-brittleness. Everyone agrees that something segregating to the boundary causes the trouble, but the nature of this material and process is not known. The first explanation is that there is a precipitation of something in the boundary; this can explain the relations between phosphorus and manganese or chromium. The other explanation is that the impurity causing embrittlement separates to the boundary but remains in solid solution.

It is difficult to decide between the two alternatives when the particles of precipitate are so small that their existence cannot be demonstrated, which appears to be the case at present. Some recent work by McLean[4] on the copper–antimony alloys indicates a possible way. Antimony has an appreciable and well established solid solubility in copper, and certain copper–antimony alloys show an 'impact transition temperature' on cooling very like the 'impact transition temperature' of ferritic steels. In alloys with 0·1–0·2% of antimony the embrittlement temperature is so low that it is possible that the embrittlement may be due to antimony coming out of solution; but there are other alloys with higher antimony contents that are brittle at temperatures at which the antimony would be expected to be entirely in solid solution. In these cases it may prove that the degree of embrittlement is dependent on the heat-treatment; if this is so, an explanation in terms of the formation of precipitates will be impossible, and the explanation in terms of segregation of dissolved antimony to the grain boundary will have to be entertained.

Mr. **J. E. Russell** (English Steel Corporation, Ltd.): In view of the many years during which metallurgists have worked on the subject of temper-brittleness, it is with some hesitation that I suggest two more theories, both of which would fit the known facts of the phenomenon.

On looking at Mr. Woodfine's excellent electron micrographs, my first reaction was: could the 'grooves' be intercrystalline cracks ? A few seconds' reflection suffices to reject the idea, but nevertheless it is feasible that they could be regions of high tensile stress set up by unequal contraction of the pre-existing austenite zones during slow cooling. The coefficient of thermal expansion varies in different crystallographic directions, so that regions of very different crystal orientation would tend to 'pull away' from each other; the ferrite crystals within the original austenite boundaries are more nearly parallel to each other, and consequently there is less disturbance of the stress system at their boundaries. The intercrystalline stresses will cause local acceleration of the etching process, giving rise to the characteristic grooves. Fast cooling would cause compressive stresses to arise inside the cooled specimen, thus counteracting the tendency of the prior austenite blocks to come apart, and giving 'tough' behaviour. Reheating such a toughened material would cause relief of the retaining stresses. The application of a slow tensile stress to an embrittled material would merely cause local boundary yielding to occur, so that no behaviour different from that of a tough material would be observed. In the impact test, however, no time is permitted for local stress adjustment and the fracture will occur along the weakened prior austenite boundaries.

The other hypothesis I wish to present tentatively is an attempt to get away from the main weakness of the boundary-segregation idea, *i.e.*, that the atoms responsible for the phenomenon must move towards the boundaries of the prior austenite regions at temperatures below about 550° C., and away from them at higher temperatures, and must do this indefinitely, however often the cycle is repeated. On the other hand, it is reasonable to suppose that the responsible atoms are arranged more or less randomly on or within the α-lattice at fairly high temperatures below A_1, and that if the temperature is allowed to fall slowly they will arrange themselves in greater degrees of order. A rapid cooling would retain the highly random distribution. Since the α-lattice is highly distorted at the prior austenite grain boundaries, and much less so at boundaries within these domains, the drive of the responsible atoms towards greater order will mean that they will tend to diffuse away from the prior austenite grain boundaries, which thus become denuded of the appropriate alloying element and hence weakened in comparison with the remainder of the material. As with the previous theory, the speed effect will suffice to explain why the phenomenon shows up on impact tests, but not on tensile tests. The process would be somewhat similar to the order–disorder changes that occur, for example, on certain silver–gold alloys; the very small percentages of alloy involved would explain why a 'superlattice' has never been observed, whereas some slight hardening of embrittled material (which is known to accompany changes of this type) has been reported from time to time.

Dr. **S. A. Main** (Hadfields Ltd.): I feel that more progress might have been made if attention had been given to certain fundamentals. To go into details would take too long; those interested may, however, be referred to a paper[5] where I endeavoured to show how not only temper-brittleness but also the other principal facts associated with the hardening and tempering of steel can result from simple basic processes known to be in operation.

It will be sufficient to indicate these processes and their

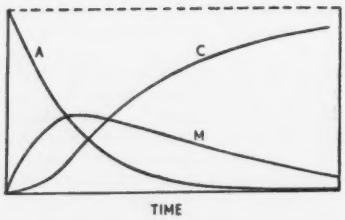


Fig. A—Progressive transformation from austenite to ferrite + carbide in tempering

general effects as follows. Austenite, at temperatures below its stable range, can change into martensite (or what will become martensite if it is allowed to remain intact down to ordinary atmospheric temperature), and martensite can break down into one of the forms of ferrite + carbide, such as sorbite or troostite. It is the simultaneous and continuous operation of these two processes which form the basis of the known phenomena of tempering.

Under isothermal conditions, the austenite breaks down and its amount at any time may be represented by a curve such as *A* in Fig. *A*, its rate of decomposition depending upon the amount then remaining. The rate of decomposition of the martensite similarly depends on the amount present at any time, but with martensite the amount present depends not only upon what has formed from the austenite but also upon how far that amount has itself been decomposed. The result is that the amount of martensite follows a curve *M*, and passes through a maximum. The amount of ferrite + carbide is represented by curve *C*. The amounts of ferrite + carbide, martensite, and austenite are naturally equivalent in total to the original amount of austenite.

The form and time scale of the diagram may vary greatly, depending on the sluggishness of the steel and on the temperature. Varying temperature introduces other changes. While the steel is cooling down during the hardening process the diagram is subject to continuous variations, but its essential character remains. When the steel is being reheated for tempering, the breakdown of any martensite remaining from the hardening process must be considered additionally to that of residual austenite. It is in studying the variations thus possible with steels of differing characteristics, when subjected to varying time–temperature relations, coupled also with a recognition of the preponderating hardness of the martensite over that of the other constituents, that the reasons for the various features observed in hardening and tempering become apparent, as indicated in the paper referred to. Revision of this paper in some details would no doubt be necessary at this date, but the general principles remain.

So far little attention appears to have been paid to this aspect of the problem, although work in progress at the N.P.L. seems to be along these lines—*i.e.*, it is concerned with what happens after the breakdown of the austenite.

One further comment is necessary. Can it not be fairly assumed that, granted that the austenite is properly formed, its carbon is very well diffused in solution, and so in a state of more or less atomic subdivision ? Thus, at the formation of the martensite, it would appear in a nascent and highly active chemical condition, avid for combination with the iron or other carbide-forming elements. Such activity must naturally depend, among other things, on the mobility of the constituents, and so become more and more restricted as temperatures approach atmospheric temperature.

Mr. **D. McLean** (National Physical Laboratory): Temper-brittleness is one aspect of the problem of the tough-to-brittle transition, which occurs in all ferritic materials that have been suitably tested. It is that aspect concerned with the influence of heat-treatment and composition on the transition temperature. There are many complicating factors involved, such as the variation of carbide particle size and the variation of grain size, but I wish to discuss the basic underlying cause.

There are two main rival theories: the precipitate one and the segregate one. The best evidence at present for deciding between these is that provided by the electron microscope, particularly Mr. Woodfine's Fig. 8. This micrograph shows no visible coalescence in the grain-boundary grooves after 128 hr. at 575° C., and yet the same steel shows marked embrittlement after only 15 min. at this temperature. We have found a similar result in work at the N.P.L. Figure *B* (i) shows the structure of a Ni–Cr steel in the tough condition taken with the electron microscope at about the same magnification (× 5000); there are no grain-boundary grooves. Figure *B* (ii) shows the material after the same etching treatment in the brittle condition developed by tempering for one day at 500° C.; the boundary grooves are marked. The same specimen is shown at a higher magnification (× 20,000) in Fig. *B* (iii). Even at this magnification, the grooves appear to be continuous, there being no convincing sign that they actually consist of minute particles of precipitate.

The material was then tempered for 2400 hr. at 500° C., and the structure is shown in Fig. *B* (iv); although the carbide particles had coalesced considerably, there was no detectable coalescence of the grain-boundary grooves. Since the grain-boundary groove effect forms fairly rapidly during tempering, the rate of diffusion must be reasonably rapid. But as there is no coalescence of the grain-boundary groove appearance during heating, the condition represented by the grooves is apparently an equilibrium condition. This would be so according to the segregate theory, but not according to the precipitate theory.

Preece and Carter prefer the precipitate theory, partly because one of their steels containing manganese failed to produce an effect with zephiran chloride as the reagent. This is similar to results which Northcott and I got, when at first we obtained little etching effect with a Ni–Mn steel, although repolishing and etching several times brought up the grain-boundary grooves clearly and readily distinguished between the two conditions, tough and brittle. Obviously the etching effect is a delicate one, since only special reagents produce it. In view of our ignorance of etching reactions, it is not surprising that the reagent fails to work or only works weakly on occasions.

Segregation of most solute atoms should occur. The driving force for it is the free energy saved by concentration at a misfit surface, such as a grain boundary. With most solute atoms the determining factor will probably be the lattice distortion surrounding the solute atom, since at the misfit surface there are larger holes which can accommodate the larger atom, and smaller holes which can accommodate a smaller one, without so much distortion. When segregation occurs, the randomly distributed isolated spots of strain surrounding the unsegregated atoms are replaced by a more or less continuous stress extending over the interface. Hence embrittlement should result.

The driving force for segregation is the free-energy change, and so the grain-boundary concentration should be represented roughly by the equation

$$C_0 e^{-Q/RT},$$

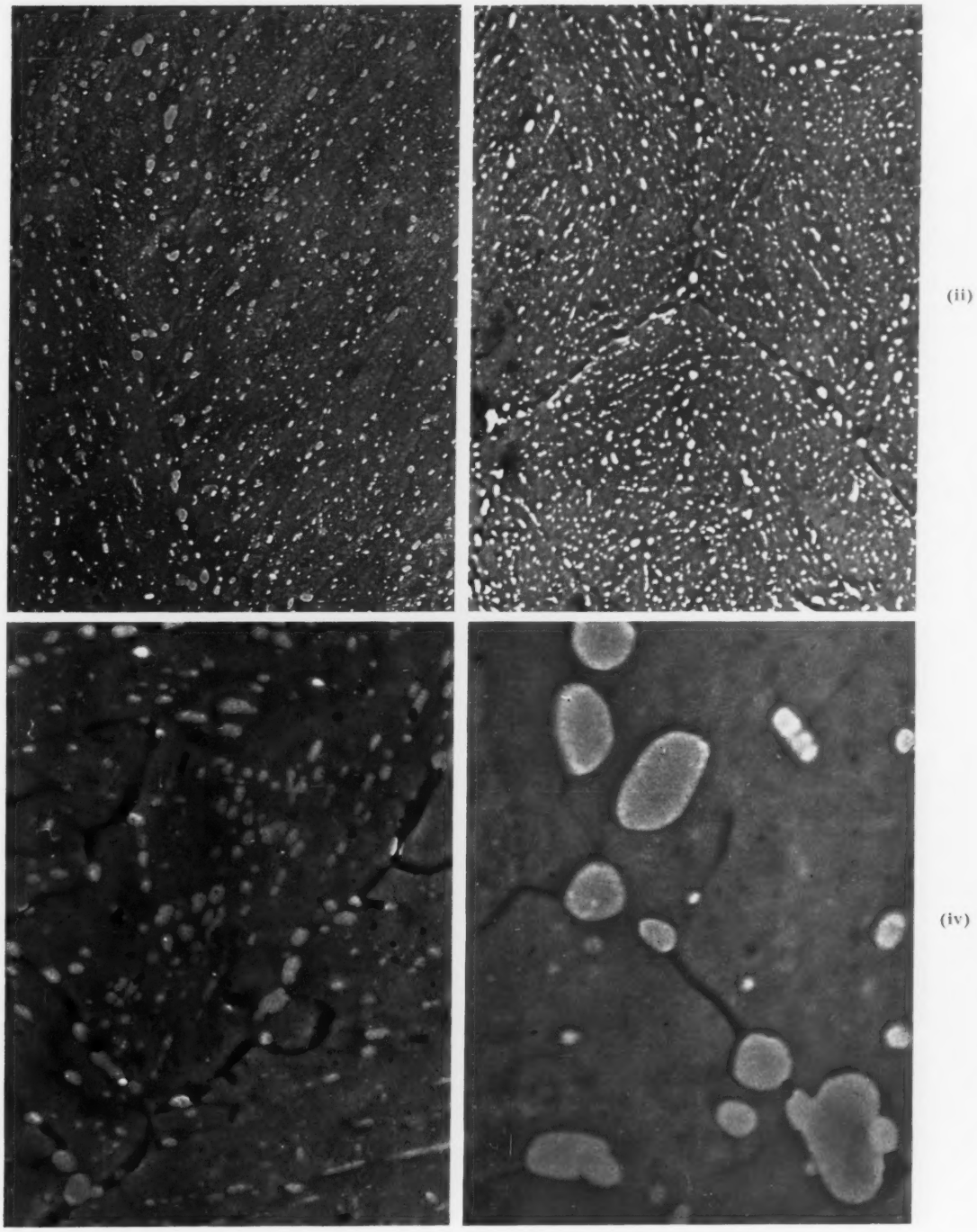


Fig. B—Electron micrographs of Ni–Cr steel. (i) Quenched after tempering at 635°C.; tough condition, Izod value 68 ft. lb. (ii) and (iii) As (i), held 24 hr. at 500°C. (within the embrittling range) after tempering at 635°C.; brittle condition, Izod value 14 ft. lb.; the black boundaries (grooves in the etched metal surface) are associated with brittleness. (iv) As (i), held for 2400 hr. at 500°C.; much growth of carbide particles, but no detectable spheroidization of boundaries

(i) and (ii) × 5000, (iii) and (iv) × 20,000

[*Discussion Temper-Brittleness*
[*To face p. 360*

where C_0 is the concentration in the grain interior. This means that as the temperature is raised, increased thermal agitation disperses the segregated atoms away from the boundary, and, as the temperature is dropped again, they resegregate. Consequently, reversibility, which is a necessary feature of a theory of temper-brittleness since it is a well-proved feature of the phenomenon, is inherent in the segregation theory.

Substitutional atoms should segregate to much the same extent in austenite and ferrite; the substitutional atoms of antimony, having an atomic diameter 30% greater than that of iron, might be expected to segregate markedly and cause considerable embrittlement; the results of Austin, Entwisle, and Smith and of Jolivet and Vidal confirm this. Interstitial atoms, since the spaces they occupy in austenite are large, should segregate only slightly in austenite, but in ferrite, where the spaces they occupy are small, they should segregate markedly.

The temper-brittle phenomenon extends mainly over the ferritic region. Considering the phenomenon in terms of the segregation theory, an interstitial element is therefore likely to be the cause. That only a few elements are responsible is indicated by the fact that the temperature which produces a strong embrittlement in a given time in so many steels is about the same (500° C.) over a very wide range of composition.

One therefore turns to carbon and nitrogen, which are ever-present in steel. At first sight, the results obtained by Preece and Carter with carburized samples appear to support the attribution of temper-brittleness to these elements, but with these results complications make this conclusion rather uncertain. On the other hand, the results on their plain-carbon steel 31 in Table I, where they obtained a negligible variation between tough and brittle transition temperatures, suggest that carbon alone does not produce the effect, and Jaffe and Buffum some years ago found the same thing. However, in plain-carbon material containing about 0·1% of carbon, quench ageing occurs after quenching from 600° C., the treatment applied by these authors to produce their tough condition, and this ageing embrittles the material considerably. Jaffe and Buffum did not guard against this complication, and Preece and Carter did not say whether they did or not. If they did not, this embrittlement will have occurred and will have raised the transition temperature which they would otherwise have got for their tough condition. Consequently, since the tough specimen actually had about the same transition temperature as the brittle specimen, one can conclude that if this complication were avoided it would have had a lower transition temperature and that therefore a temper-brittle effect did occur.

Mr. Tipler and I recently conducted similar experiments in which we endeavoured to guard against this complication by storing in Drikold for the short time that elapsed between quenching and testing. We used Swedish iron of an almost identical composition to that used by Preece and Carter as their basis material. When air-cooled it had a transition temperature of 0° C. When reheated to 690° C. and slowly cooled, the transition temperature rose to 95° C. When slowly cooled specimens were reheated to between 400° and 600° C. and quenched (being stored before testing), the transition temperature was lowered to 75° C. These results show that a very marked variation in transition temperature is produced by varying heat-treatment in fairly pure plain-carbon material.

Mr. **A. L. Carr** (Mond Nickel Co., Ltd.): All the present investigators embrittled their specimens isothermally because, in this way, the embrittling reaction may be controlled more closely than during continuous cooling from the tempering temperature. In addition, they determined the impact transition temperatures of their steels and assessed the degree of embrittlement by the shift of transition temperature, although different criteria have been used by the different workers to assess transition temperatures. In my own work on temper-brittleness I used 10-mm. square Izod **V**-notch impact specimens tested in a Charpy machine, and I prefer to use the same criterion for transition temperature as Mr. Woodfine, *i.e.*, the lowest temperature at which a 100% fibrous fracture is obtained. Curves of percentage fibrous fracture *versus* test temperature generally appear to have less scatter than curves of impact value *versus* test temperature, and the onset of brittle fracture is more readily determined than is some percentage of the maximum impact value.

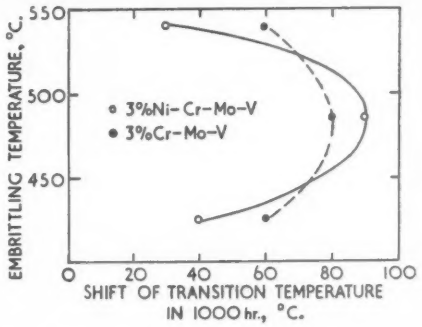


Fig. C—Effect of embrittling temperature on the isothermal temper-embrittlement of two steels

On p. 233 of his review, Mr. Woodfine comments that it appears from the literature that different steels have different temperatures of maximum embrittlement. Our work shows that although two steels may have approximately the same temperature of maximum embrittlement, the shape of their embrittlement curves is often significantly different.

Figure *C* illustrates this point. The two steels examined, a 3% Ni–Cr–Mo–V steel and a 3% Cr–Mo–V steel, corresponding roughly to En 27 and En 29, respectively, both show, after an embrittling time of 1000 hr., a maximum embrittlement at about 485° C. The shift of transition temperature of the 3% Ni–Cr–Mo–V steel is much less when embrittlement occurs after 1000 hr. at 540° or at 425° C. The shift for the 3% Cr–Mo–V steel is also less at these temperatures, but the reduction is not so marked, and the apparent susceptibilities of the two steels may be reversed according to the temperature of isothermal embrittlement.

Mr. Woodfine and Professor Austin and his colleagues present results on the effect of hardness on susceptibility to embrittlement and conclude that prolonging the tempering time lowers the susceptibility to embrittlement of a number of steels. Professor Austin's results are compared with those of Buffum and Jaffe, whose conclusions are possibly in doubt owing to their use of low tempering temperatures of about 500° C. to obtain the higher hardness values.

I have obtained a wide range of hardness values in a 3% Cr–Mo–V steel by varying the tempering time at 600° and 740° C. Both these temperatures are much higher than the embrittling temperature used (485° C.), and it is unlikely that appreciable embrittlement occurred during tempering. Figure *D* shows the impact transition temperatures of this steel before and after embrittlement plotted against hardness, which varies from 200 to 380 D.P.N. Susceptibility to embrittlement is substantially

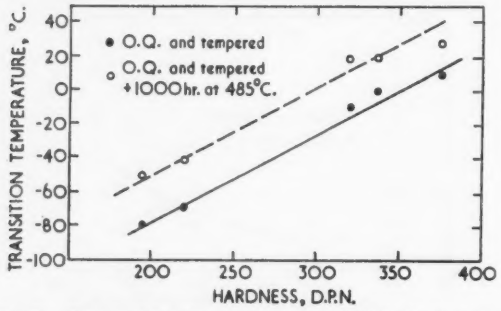


Fig. D—Effect of hardness on susceptibility to temper-brittleness of a 3% Cr–Mo–V steel

constant over the range of hardnesses covered. I am aware that this is a steel of only slight susceptibility and that the results may not be sufficiently conclusive, but a number of less complete sets of results on other steels of greater susceptibility also show little difference in susceptibility at different hardness values. However, a greater difference might be shown with a steel having a greater susceptibility to embrittlement.

Professor Austin's results on the effect of antimony confirm on the En 23 type of steel the conclusions of Jolivet and Vidal on a chromium steel. Some time ago I examined the effect of antimony on a nickel steel made in a small H.F. furnace. Figure *E* (i) shows the very marked effect of 0·09% of antimony on the temper-embrittlement properties of this 3% Ni steel. The steel with no antimony addition had an impact transition temperature of − 30° C., and this was practically unaffected by reheating for 24 hr. at 520° C. The antimony steel, made by splitting the heat and adding antimony, had impact properties in the tough condition that were almost the same as those of the antimony-free steel. After 24 hr. at 520° C. the antimony steel underwent a very marked embrittlement, which is shown by the shift of the transition temperature from − 25° C. to + 100° C. and by the reduction of the impact value above the transition temperature from about 70 to about 40 ft.lb.

This test was repeated on a further pair of steels, as shown in Fig. *E* (ii). In this experiment the embrittling treatment at 520° C. was prolonged for the antimony-free steel (0·02% Sb) for 1000 hr., and resulted in a transition temperature shift of 50° C. The Sb-bearing steel, after only 24 hr. at 520° C., was again severely embrittled; the transition temperature was raised from + 30° to + 150° C., and the maximum impact value was approximately halved. These experiments provide a further example of the marked influence of antimony on temper-brittleness.

The paper by Professor Preece and Dr. Carter is of fundamental interest and value, because these investigators used high-purity materials. It seems, however, to be very common for the effects of the slight amounts of impurities left to become greater as alloys become purer, and although the authors went to great trouble to control the oxygen content of their alloys, there may still be one or two other elements present that have a disturbing effect on results. Temper-brittleness is attributed by them mainly to the presence of carbon. Among the experimental work to support this idea, we find on p. 394 the effect of lowering the carbon content of an alloy from 0·21% to 0·08%. The transition temperature of the 0·08% C alloy in the tough condition is higher than that of the 0·21% C alloy, although it is 50 D.P.N. softer. These two alloys probably have the same type of structure, and a fall in hardness would be expected to correspond with a fall in transition temperature. Presumably the substantially carbon-free alloys in Table VIII are even softer, although they may have a different structure, but their transition temperatures in the tough condition are high. These results seem to suggest that in the absence of carbon there is some embrittling effect on the steels in the so-called tough condition other than that due to temper-brittleness or to oxygen, which the authors have eliminated as far as possible, and that the present results do not conclusively demonstrate that the temper-brittleness effect is mainly due to carbon.

All the authors seem to agree that embrittlement occurs by some form of grain-boundary segregation. My own view, which agrees more closely with that of the Cambridge workers, is that the segregating elements are the trace-elements arsenic, antimony, phosphorus, or tin, of which antimony is by far the most important, plus, possibly, other trace-elements, and that the effect of the major alloys is to modify the segregation of these trace-elements. The experimental verification of this hypothesis presents considerable difficulties, although several possible lines of investigation have been suggested in the paper by Austin, Entwisle, and Smith.

Mr. **A. M. Sage** (British Iron and Steel Research Association): The authors are to be congratulated on providing so much interesting data on the compositions

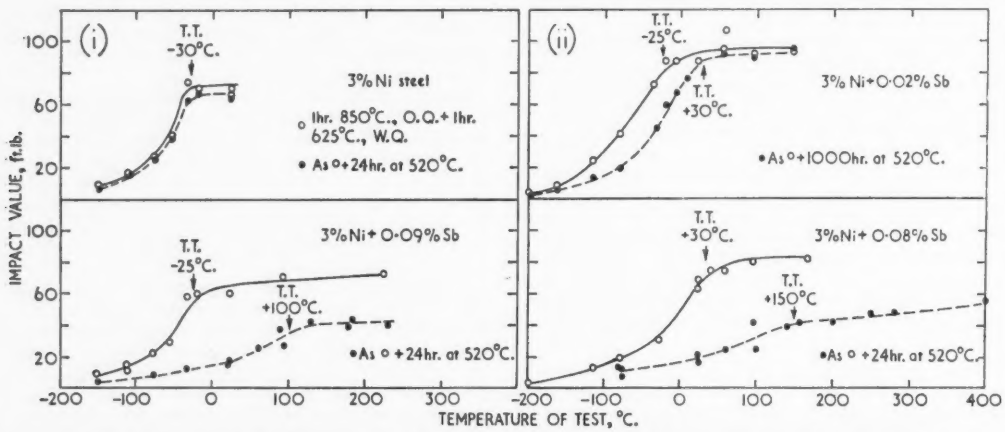


Fig. E—Effect of antimony on the isothermal temper-embrittlement of 3% Ni steel

and conditions of steel under which temper-brittleness can be produced and on stimulating our thoughts on a subject that has defied a satisfactory theoretical explanation for so long.

Many of the experimental results should, however, be treated with great caution. The conclusions are very largely based on transition temperatures derived from impact-energy/temperature curves, and four important considerations in the determination of transition temperatures from impact tests over a temperature range appear to have been overlooked. Firstly, a notoriously wide scatter is found in impact testing unless certain precautions are taken. It is therefore surprising that the authors have apparently been satisfied to base their work on single impact tests at a given temperature. Secondly, one of the most important factors contributing to the usual wide scatter in impact-test results is the method by which the notch is made in the test piece. The results given below for impact tests carried out in one Charpy machine on specimens of the same carbon steel machined in two independent workshops indicate the large effect that variations in machining conditions can have.

Specimens machined by: Machine Shop No. I	Ft. lb.	Machine Shop No. II
18		27
16		35
27		35
22		33
16		31
14		31
16		27
18		29
20		27
18		29

This variation is probably due to differences in the condition of the cutter used for machining the notch and the amount of work-hardening produced at the root of the notch. The same variation could probably be produced in one machine shop through wear of the cutter or through the use of different cutters. Unless precautions were taken to guard against this effect, therefore, the actual impact values used by the authors should be treated with reserve.

Thirdly, even if the impact values are accepted, the considerable scatter noted on many of the curves given by Preece and Carter and on some of the curves given by Woodfine would allow alternative transition curves to be drawn. This could significantly alter the embrittlement figures that have been quoted. The same comment would no doubt apply to the results obtained by Entwisle, and it seriously detracts from the value of the papers by Austin, Entwisle, and Smith, and by Preece and Carter that in the former no transition curves and in the latter only some of the transition curves are quoted.

Fourthly, the assessment of embrittlement for a steel will depend on the definition adopted for transition

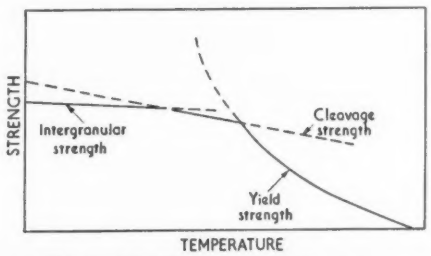


Fig. F—Modified Ludwik diagram

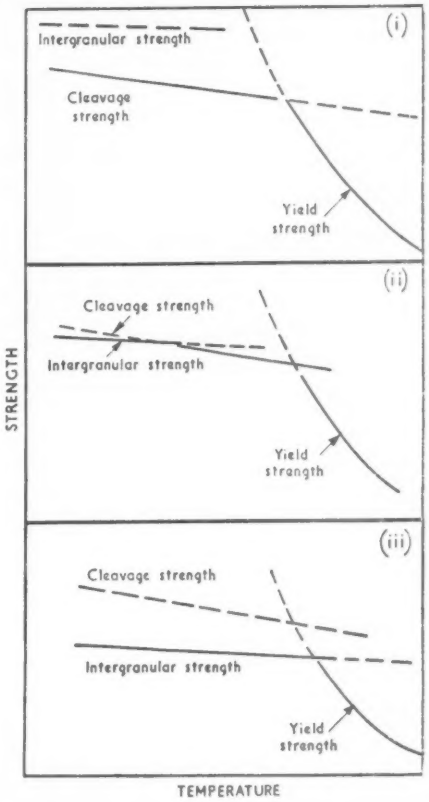


Fig. G—Modified Ludwik diagram for (i) unembrittled, (ii) partially embrittled, and (iii) fully embrittled steels

temperature. In this case Woodfine's adoption of the lowest temperature at which 100% fibrous fracture was observed is theoretically sound; no definition is given by Preece and Carter, and the value of the paper would be considerably increased if a definition were provided. Entwisle's definition based on the temperature for arbitrary impact value, although suitable for specification purposes, is not particularly suitable for research work as it takes no account of the slope of the transition curve.

Woodfine's attempt to relate the results of notch-bar impact tests to the tensile properties is interesting, but there appears to be some confusion between his definition of transition temperature and the diagram in Fig. 20*a*. The behaviour of a steel at temperature T_1 is typical of a steel at any temperature above T_2, and the behaviour of a steel at temperature T_3 is typical of a steel at any temperature between T_4 and T_2. Surely, therefore, T_2 is the transition temperature (defined as the lowest temperature at which 100% tough fracture is produced) and the transition temperature range is between T_4 and T_2. In Fig. 21, in fact, it appears that the author has adopted T_2 as the transition temperature.

The attempt to show the intergranular and cleavage brittle strengths on the stress/strain/temperature diagram is also useful, but this is really only a development of the well known explanation of the transition curve by Ludwik described by Joffé and his co-workers[6] and by Davidenkov and Wittmann,[7] which it is surprising that Woodfine does not mention in his review. Woodfine's

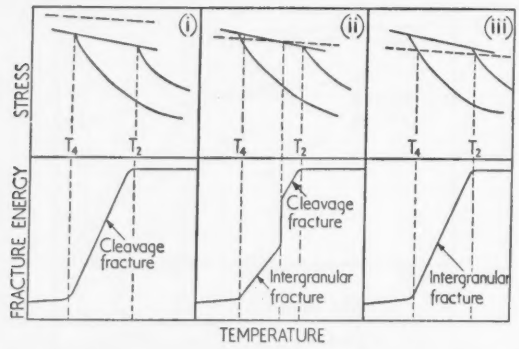


Fig. H—Diagrammatic derivation of transition curves for (i) unembrittled, (ii) partially embrittled, and (iii) fully embrittled steels

representation in Fig. 21 implies the addition of a line representing the variation in intergranular strength with temperature to Ludwik's original diagrams as shown in Fig. *F*. The extent of the temper-embrittlement will depend on the location of the curve representing the intergranular strength with respect to the other two curves, and Figs. *G* (i)–(iii) represent the position of this curve for a steel non-embrittled, partially embrittled, and fully embrittled, respectively. Figure *G* (ii) is similar to Woodfine's Fig. 21, except that Woodfine has drawn the intergranular and cleavage strength curves (or planes) parallel, for which there appears to be no justification. It is a pity that Woodfine has drawn these planes parallel because it masks a probable explanation for the unusual shape of some of his transition curves. If his Fig. 21 is redrawn with the intergranular embrittlement curve at three levels to represent non-embrittlement, partial embrittlement, and full embrittlement, and if the expected fracture-energy/temperature curves are projected as shown in Fig. *H* (i)–(iii), it will be observed that the transition-temperature range for a partially embrittled steel can be considered in two portions: the lower-temperature portion, in which the brittle fracture is intergranular, and the high-temperature portion, in which the fracture is by cleavage. It will also be observed that the transition curves for partially embrittled steels shown in Figs. 10 and 11 of Woodfine's paper tend to show these two portions with different slopes in the transition-temperature range. In his description of the appearance of the fractures of partially embrittled specimens, Woodfine mentions that some of the fractures exhibited cleavage facets. It would be interesting to know whether the presence of these predominated in specimens tested at the higher temperatures in the transition range.

The theoretical explanations for the cause of temper-brittleness that have been put forward on the basis of the very careful metallography and electron-microscopy described in the three papers have much to commend them in preference to earlier theories, which were largely based on the assumption that carbides or nitrides were precipitated at the grain boundaries. In the light of the results of these three papers it does appear that temper-brittleness occurs through the segregation of chromium or manganese atoms at the austenite grain boundaries and the subsequent segregation of carbon atoms at these boundaries (as well as other ferrite boundaries). The presence of nickel, arsenic, antimony, or phosphorus appears to increase the susceptibility of steels prone to this effect, but these elements by themselves do not produce temper-brittleness. These explanations are, however, *ad hoc*, and it would be useful if the authors could suggest why these elements and not others behave in this way. It will be observed that these elements which produce temper-brittleness or increase the susceptibility of steels to this brittleness form substitutional solid solutions with iron, and consideration of the atomic radii of these elements, given below, shows that the elements with atomic radii close to that of iron have a greater effect than those whose radii are not so close.

	Element	Atomic Radius	Remarks
	Fe	0·75	
Elements giving rise to temper-brittleness	Mn	0·80	Form substitutional solid solutions with Fe; carbide formers
	Ti	0·68	
	Mo	0·66 or 0·62	
	Cr	0·52	
Elements increasing the susceptibility of temper-brittle steels	Ni	0·69	Form substitutional solid solutions with Fe; non-carbide formers
	Sb	0·62	
	As	0·47	
	P	0·34	

The elements that cause temper-brittleness are in addition carbide formers, whereas those that only increase the susceptibility of steels subject to temper-brittleness are not.

The papers imply that the occurrence of temper-brittleness is determined by the behaviour of the carbon atoms. Two mechanisms by which the brittleness is produced can be postulated:

(i) In all steels at temperatures above about 300° C. the energy of these atoms increases, so that they are able to migrate to the grain boundaries. When substitutional atoms having a high affinity for carbon are present in the grain boundaries the carbon atoms are anchored and the steel is embrittled. At temperatures above 600° C. the mobility of the carbon atoms further increases, so that they no longer remain anchored.

(ii) When atoms of substitutional carbide-forming elements are present at given boundaries, carbon atoms at temperatures above 300° C. have sufficient mobility to be attracted to the carbide-forming elements.

A study of the movement of radioactive carbon atoms at non-austenitic ferrite boundaries might determine which of these hypotheses provides the most likely explanation.

None of the papers attempts to explain the mechanism by which molybdenum by itself gives rise to temper-brittleness and when present in Ni–Cr steels prevents temper-brittleness. Molybdenum has an atomic radius of 0·66 and forms carbides. The similarity of its behaviour to that of manganese and chromium is therefore not surprising. If, however, it can be assumed that

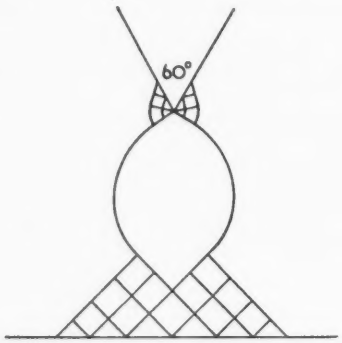


Fig. I—Predicted slip-line field for the bending of a notched bar

its tendency to segregate to austenite boundaries is greater than that for chromium and manganese, the austenite grains in a Ni–Cr–Mo steel would contain a concentration of molybdenum atoms at the boundaries inside which there is a concentration of chromium atoms. During the embrittling treatment the carbon atoms will segregate towards the boundaries, but will be anchored by the chromium atoms, which have a high affinity for carbon. The carbon atoms are thus prevented from reaching the molybdenum atoms or the grain boundaries, and the steel is therefore not embrittled.

Entwisle refers to the overageing effect of an embrittled steel subsequently heated at 620° C. for up to 80 min. No further embrittlement takes place after 40 min., which he attributes to the embrittling effect of treatment at this temperature. On the basis of the above hypotheses the failure to remove the embrittlement completely from the steel could be explained by the fact that the carbide-forming elements in the grain boundaries still had some attraction for the carbon atoms, and a portion of them remained anchored in spite of their increased mobility.

Mr. **B. E. Hopkins** (National Physical Laboratory): In discussing segregation at grain boundaries, Austin, Entwisle, and Smith give the impression of having been at some pains in finding other examples of a connection between molybdenum and phosphorus, and have quoted the effect of molybdenum in decreasing the banding and segregation in manganese steels. In the alloy cast-iron field it is well known that phosphorus interferes with molybdenum in producing an acicular (*i.e.*, intermediate) structure on continuous cooling. Rote and Wood[8] showed that this was due to the molybdenum segregating to the phosphide eutectic, and they give some examples where substantially all the molybdenum is so tied up. I think this is a very good example of association of molybdenum and phosphorus.

Dr. **B. B. Hundy** (B.I.S.R.A.): On p. 252 of his paper, Woodfine discusses the theory of the notched-bar impact test. I do not disagree fundamentally with his analysis, but I would like to amplify one of the points raised in this section. My colleague, Mr. A. P. Green, has recently analysed the yielding of a notched bar during bending.[9] His solution is for a plastic–rigid material, bent in plane strain by pure couples at the ends of the bar; these conditions differ slightly from those in the impact test, but we consider that the mode of deformation is certain to be similar in the two cases. The slip-line field obtained is shown in Fig. *I*; this type of solution holds up to a notch angle of 115°. If the bar is bent to open the notch, the two small regions of deformation at the root of the notch are in tension and the region at the plane side of the bar is in compression. There is no neutral point or axis in this solution; the ends of the bar rotate around the solid pivot enclosed by the two circular slip lines. Figure *J* shows that the actual mode of deformation in a real metal is very close to that predicted by theory. This etched pattern was obtained by bending a mild-steel notched bar and then ageing for 30 min. at 250° C. A section was cut from this and was etched in Wazau's reagent to darken the deformed regions.

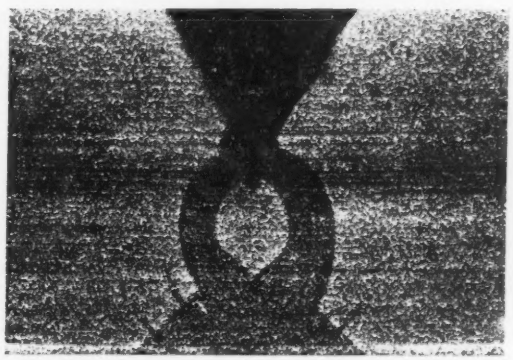


Fig. J—Pattern of deformation obtained when a bar is bent plastically

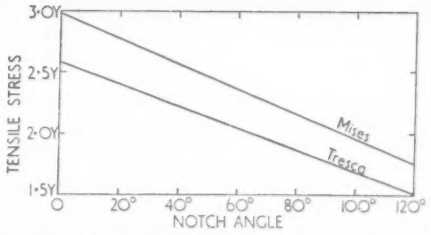


Fig. K—Calculated tensile stress at the root of a no tched-bend specimen

By applying simple plasticity theory to the region round the root of the notch, the tensile stresses acting there at the start of plastic deformation can be calculated. These tensile stresses are known to govern brittle fracture in steel and are usually expressed as a stress-raising factor σ/Y, where Y is the yield stress in uniaxial tension. The tensile stress acting at the root of the notch is shown in Fig. *K* for a range of notch angles from 0 to 120°. The stress-raising factor depends to some extent on whether we assume that the metal obeys the Tresca or the Mises criterion of plastic yielding. In general, it is thought that an average of the two values will be suitable, and Woodfine's estimate of a stress-raising factor of 2 is fairly close to that of 2·35 predicted by this theory. The stress-raising factors resulting from different-shaped notches can be calculated similarly to give the following results:

Charpy keyhole notch	1·9
DMVr notch	1·96
Mésnager notch	1·98

This analysis should lead to better understanding of the effect of notch geometry on the transition temperature of steel.

Mr. Woodfine claims that brittle fracture will first appear in notched-bar specimens at the temperature T_1, and that part of the fracture should remain ductile down to temperature T_3 (Fig. 20). Would he amplify his reasons for these claims ?

CORRESPONDENCE

Mr. **B. E. Hopkins** (National Physical Laboratory) wrote: Preece and Carter are to be congratulated on their courage in attacking the problem of temper-brittleness by using a base iron of good purity and making steels of controlled composition. Their interpretation of some of their results, however, needs some discussion.

Unfortunately, a number of details that would be of value in assessing the results are not given in the paper. The Swedish iron used had a substantial oxygen content of 0·044%. Melting in a so-called vacuum might well increase the oxygen content. The carbon contents of the purest commercial grades of ferro-alloys added are not given, but these might presumably have been insufficient to remove most of the oxygen from the iron. The fact that the alloys as made are stated to be carbon-free further suggests that they might have substantial oxygen

contents. The alloys made with the spectrographically pure manganese would certainly be expected to have oxygen contents of at least that of the Swedish iron because of the low carbon content of the manganese. Some oxygen was probably removed during the carburization procedure, but since the rate of diffusion of oxygen outwards at 950° C. is about one-thousandth of that of carbon inwards, it appears from first inspection that the resulting steels might well have contained considerable oxygen. Were oxygen determinations made at any of these stages or did microscopic examination reveal the presence of iron-oxide particles ? The brittle fractures of the unembrittled steels listed in Tables I, II, and IV are stated to be transcrystalline. If these fractures contained no trace of intergranular failure and the steels actually contained substantial amounts of oxygen, we have to deduce that the introduction of carbon in the solid state can counteract the effect of oxygen in promoting failure of iron along grain boundaries. This would be an important effect, and the mechanism by which it occurs would be of great interest; are we therefore justified in coming to this conclusion ?

In the section of the paper dealing with decarburization the authors confirm our own work in finding that oxygen is effective in producing intergranular weakness, and they are to be congratulated on the attempt they made to obtain low oxygen contents by their decarburizing procedure. As no oxygen contents are reported, however, how did they know that they had achieved their aim ? In spite of the statement that treatment for a week in dry hydrogen at 950° C. " removed oxygen sufficiently in many cases to eliminate the persistent intercrystalline brittle fracture due to oxygen " (p. 395), only one of the five alloys in Table VIII gave a completely cleavage fracture in the unembrittled state. From our own experience an iron–2% manganese alloy should give a brittle fracture that is entirely cleavage if the oxygen content is sufficiently low, but alloy 44 after decarburizing gave a mainly intercrystalline brittle fracture in the unembrittled state.

The conclusion that temper-embrittlement does not occur in the absence of carbon may be correct but it is hardly justified on the evidence presented in this paper. Two of the alloys in Table VIII (22 and 42) were not susceptible even with carbon present, so that they cannot be adduced as proof that removal of carbon eliminates susceptibility to temper-brittleness. It may be significant that these non-susceptible alloys are just the ones that give entirely cleavage or mostly cleavage fractures in the unembrittled condition. Since the other three alloys in the same Table give a fracture that is mainly or wholly intercrystalline in the so-called unembrittled state, and since the authors adopt an intergranular fracture as an essential criterion of temper-brittleness, is it not possible that these alloys are already in an embrittled condition ? The fact that the impact transition temperatures are much (mostly over 100° C.) higher in the decarburized condition than with carbon present further suggests that this is so. The results obtained on the decarburized alloys may only be a manifestation of the interaction between small amounts of certain elements. The onset of intergranular brittleness by decarburization in hydrogen also occurs in iron in the absence of chromium, manganese, and phosphorus, and heat-treatments of iron containing $< 0{\cdot}002\%$ of oxygen and $< 0{\cdot}006\%$ of carbon can make the material weak along the grain boundaries. The etching evidence given in support of their conclusion concerning carbon may not be significant because it is not of universal application, as the authors themselves have shown; the etchants used do not reveal the susceptibility in manganese-containing steels, so why should they in the decarburized alloys ? Unless the mechanism of the etching effect is understood, one has to be careful about using it as supporting evidence. In view of the objections that can be raised against the interpretation of the results on the decarburized alloys, it is desirable that the supplementary evidence about the three normally susceptible chromium-containing alloys be given in detail by the authors.

In the work on high-purity iron alloys at the N.P.L., we have found that phosphorus very readily induces intergranular brittleness in iron. The effect is greatest in alloys that are quenched from the austenitic condition and progressively decreases as the rate of cooling decreases, but it is not entirely removed, even by extremely slow cooling. It follows that the apparent increase of susceptibility to temper-brittleness caused by manganese and chromium may be due to their not being very potent in removing the effects of phosphorus and other impurities rather than to their actually increasing the effect. This contradicts the results on alloys 31 and 30 in Table I, from which it is seen that the addition of $0{\cdot}036\%$ of phosphorus to an iron–carbon alloy does not produce temper-brittleness; this is a result I do not understand. Since intergranular brittleness can be produced in iron by various elements, of which phosphorus is only one, it might be more profitable to regard temper-brittleness as only a part of the whole problem of why intergranular brittleness and a reduction in brittle fracture stress should occur under certain conditions. The fact that temper-brittleness develops at normal tempering temperatures might be incidental, and it might still be essentially the same phenomenon if the temperatures of development are outside the normal tempering temperature ranges.

It is difficult to see what the authors have gained by devising the modified susceptibility factor S, especially as the assumptions involved are questionable. For a given rise in impact transition temperature on embrittlement the value of S is not constant, but it is smaller the higher the transition temperatures. From the point of view of the usefulness of the factor, it would seem to be undesirable to have a smaller value of S for a rise in transition temperature of 50° C. in the more dangerous temperature range 0–50° C. than for the same rise from − 50° to 0° C. The conclusion to be drawn from the authors' discussion of the modified susceptibility S is that it is not a good substitute for a direct determination of the change in brittle fracture stress by means of tensile tests at low temperatures.

Mr. **G. Burns** (Admiralty Materials Laboratory) wrote: In Tables III and V of their paper, Austin, Entwisle, and Smith record that the tensile fractures of many of the steels tested showed radial cracking in greater or less degree, and on p. 379 they refer to Hollomon's conclusion that this phenomenon was associated with temper-embrittlement in a manganese–molybdenum steel.

In the writer's experience, radial cracking in tensile fractures is a very common phenomenon when testing material that has been carefully heat-treated in small sections, but it is rarely or never observed in material heat-treated in moderately large sections.

The impression formed during the heat-treatment and testing of many hundreds of samples from a substantial range of low and moderately alloyed steels is that radial cracking in the tensile fracture is associated with thorough hardening in the quenching stage of heat-treatment. In obtaining hardness numbers of 600 or over in all their steels as-quenched, the authors have got close to the maximum hardness attainable in steels containing about $0{\cdot}4\%$ of carbon.

Any association of this phenomenon with temper-embrittlement is rendered doubtful by its being observed often in steels not in the embrittled condition and which, on the basis of a cooling rate of 20° C./hr. were not susceptible to temper-brittleness.

AUTHORS' REPLIES

Mr. **B. C. Woodfine** (in reply): Mr. Russell has added two more theories of temper-brittleness to the list given in the 'Review,' but his suggestion that the embrittlement results from unequal thermal contractions in different crystallographic directions cannot be correct, because the thermal expansion of ferrite is isotropic. In proposing that temper-brittleness is an order–disorder change, Mr. Russell finds it a weakness of the segregation theory that the responsible atoms are required to diffuse to the grain boundaries at temperatures below 550° C. and away from them at higher temperatures, and that this cycle must be capable of indefinite repetition. However, as Mr. McLean has pointed out, temper-brittleness is a reversible phenomenon, and so any proposed theory must also be reversible. This condition is, in fact, fulfilled by Mr. Russell's order–disorder change, in which the responsible atoms must diffuse away from the boundaries below about 550° C. and towards them again above this temperature. Although a denuded grain-boundary region would make it easier to explain the production of grain-boundary grooves by the various etching reagents, it seems unlikely that such a region will occur by the diffusion of solute atoms into the matrix, because all the experimental evidence is in favour of the opposite process. In the low-alloy steels that are susceptible to temper-brittleness the occurrence of an ordered structure also appears improbable, in view of the relatively few solute atoms present. If at high temperatures the solute atoms are distributed at random through the grains, their distances of separation will in general be far too large for any superlattice to be established by either short- or long-range forces. Order–disorder changes are found in those compositions that approximate to simple formulæ such as AB or AB_3, and not in dilute solutions.

Mr. Russell states that temper-brittleness is revealed by the notched-bar impact test and not by (room-temperature) tensile tests because of the 'speed effect,' but since the embrittlement can be demonstrated by the slow-bend test this is clearly not the case. The analysis of the notched-bar test given in my paper attempted to show that the difference in behaviour can be explained by the 'notch effect,' *i.e.*, the triaxiality in the stress distribution which occurs below a notch.

Mr. Russell refers to a slight hardening which he says sometimes accompanies temper-brittleness, but in fact published work shows that where care has been taken to ensure that the temper-brittle and non-temper-brittle specimens have had the same amount of tempering, the hardness is not affected. In one case where hardening was reported, the specimens had been heated above Ac_1.

Mr. Russell refers to an order–disorder change in Ag–Au alloys, but as far as I am aware these alloys do not show such a change; presumably Mr. Russell meant the Cu–Au alloys.

Mr. McLean has given an excellent summary of the segregation hypothesis, and it is gratifying to find that his electron micrographs show the same features as those in my paper. Of particular interest is the micrograph from the steel embrittled for 2400 hr. at 500° C., which clearly demonstrates that the grain-boundary grooves show no sign of the coalescence that would be expected if they were due to a grain-boundary precipitate.

The results obtained by Mr. Carr for the isothermal embrittlement of the Ni–Cr–Mo–V and Cr–Mo–V steels are of great interest, because they illustrate the difficulties involved in comparing the susceptibilities of different steels to temper-embrittlement. It is apparently necessary to determine the complete time/temperature/embrittlement characteristics of each steel to obtain a reliable comparison, and this procedure unfortunately requires much time and labour. The hardness/embrittlement results show that the temper-embrittlement developed by a given treatment would appear to be independent of the hardness, and this provides additional proof that the 'overageing' in steel *K* is not the result of softening during the tempering treatments (*see* p. 244 of the paper). Mr. Carr's results also indicate that the decreasing embrittlement of steel *K* after prolonged tempering at 650° C. is not connected with the drop in hardness, and they thus indirectly support the view that this is the result of changes in the alloy content of the ferrite.

Mr. Sage questions the accuracy of the notched-bar impact results and quotes some rather alarming figures to illustrate his points. However, I cannot agree with his somewhat pessimistic view of the position. The scatter in any group of fracture-energy results is due to a number of causes, including (*a*) heterogeneity in the material, (*b*) errors in temperature measurement and changes in the temperature of the specimens during testing, (*c*) differences in specimen or notch geometry, and (*d*) errors in testing, particularly in positioning the specimens. The scatter from the first of these cannot be avoided, and is responsible for the curves in Figs. 18*c* and 19*a* and *b*. In such cases it is probably better to draw a band to enclose the results instead of a single curve as has been done. However, provided that the steel is reasonably homogeneous the scatter in the results should not be very great if adequate precautions are taken in machining and testing the specimens. This is often not the case, as was demonstrated at the beginning of the research, when specimens that had been prepared by a machine shop were tested for the author in a works' laboratory; the resulting scatter was appalling. All the subsequent specimens were machined and tested personally by the author, and it was found that when particular care was taken to grind the specimens perfectly square with the dimensions controlled to ± 0·001 in. and when the subsequent testing was carefully carried out, the results were much more reproducible. With a homogeneous steel and due care in testing it is considered that the transition temperature can easily be determined to ± 2° C. The main reason for only breaking one specimen at each testing temperature was economy in time and material, but it is felt that the relatively small scatter in the results justifies the procedure. Incidentally, without using a very large cooling bath or an elaborate cryostat a number of specimens broken in succession will in fact be tested at slightly different temperatures. The accuracy of the testing procedure is best illustrated by the results in Fig. 11, where the results for three separate groups of steel *K* in the unembrittled condition are plotted with different symbols on the same graph (the curve in question has a transition temperature of − 96° C.); these groups were heat-treated, machined, and tested quite separately at widely spaced intervals of time and yet the results lie on the same fracture-energy curve with very little deviation.

I disagree with Mr. Sage that one of the most important factors in producing a wide scatter in notched-bar impact results is the method by which the notch is cut in the specimens; it has been shown by Kahn, Imbembo, and Ginsberg[10] that neither the transition temperature nor the maximum fracture energy was altered when the specimens were notched by a single cut instead of by

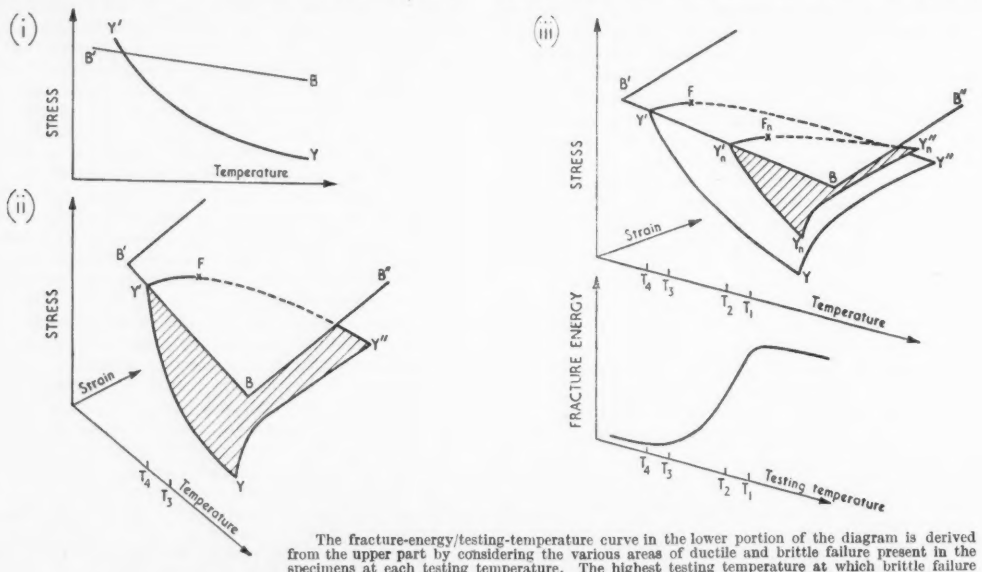
three separate cuts. Part of the scatter in the results quoted by Mr. Sage may be due to differences in the actual shape of the cutters, but, assuming the steel to be homogeneous, I would suggest that the variation is partly the result of generally bad machining, but principally arises from failure to control the testing temperature. The magnitude of the fracture energies involved suggests that the tests were made within the transition range of the steel, where small variations in the testing temperature would produce widely different results. It has been found by experience that if consistent results are to be obtained it is necessary to carry out even the room-temperature tests using a constant-temperature bath. The two groups of specimens were presumably tested on the same machine, because if this was not the case the striking velocities of the machines might have been different, which would lead to a slight relative displacement of the transition ranges. If the steel is homogeneous, no amount of care in preparing and testing the specimens will give consistent results.

Mr. Sage comments that the scatter in some of the fracture-energy curves would enable alternative curves to be drawn, thus altering the embrittlement results quoted, but if the transition temperature is defined as the lowest temperature at which the fracture is 100% ductile the actual shape of the curve is immaterial. This is a very practical advantage of the definition, since if the detailed shape of the transition curve is not required, the number of specimens that have to be tested is greatly reduced.

It appears from the observations made by Mr. Sage and later by Dr. Hundy that Fig. 20*a*, which was drawn to show the derivation of the fracture-energy/testing-temperature curves from the stress/strain/temperature properties of the material is not very clear. The diagram has been redrawn in Fig. *L* to show the yield-stress surfaces, and it is hoped that this will clarify the theory.

In referring to T_2 as the transition temperature Mr. Sage has overlooked both the effect of strain on the yield stress and the fracture stress, and the fact that brittle fracture can occur after some plastic deformation has taken place. Temperature T_1 is the highest temperature at which the Y_n/strain/temperature surface meets the brittle-strength/strain/temperature surface, and hence it is the highest temperature at which brittle fracture is found in the notched-bar impact specimens. Thus, T_1 is the transition temperature as originally defined. At temperatures above T_1 the two surfaces do not intersect and the material with a yield stress of Y_n finally fails not by brittle fracture but by a ductile form, which does not obey a maximum tensile stress law. The specimens will show a completely brittle fracture at T_3, although this will be preceded by some plastic deformation. Thus, the actual transition range extends from T_1 to T_3. Brittle fracture in the absence of any plastic deformation occurs at T_4.

In Fig. 21 the strain axis was omitted to give a simplified diagram, but the caption unfortunately implied that T_2 was the transition temperature instead of T_1, which lies outside the plane of the diagram. However, the displacements of T_1 and T_2 are approximately the same. It was not intended to imply that the B_i and B_c surfaces were necessarily parallel, and it would have been better had they not been drawn so. As Mr. Sage has shown in Figs. *G* and *H*, by altering the positions and slopes of the various surfaces it is possible to account for a transition between ductile and cleavage fracture followed by a second transition between cleavage and intergranular fracture. By rearranging the surfaces the sequence ductile–intergranular–cleavage could be explained. However, I do not think that such double transitions are likely to occur in temper-brittle steels, and in the partially embrittled steels which contained both types of fracture the relative proportions of each appeared to be the same throughout the transition range.



The fracture-energy/testing-temperature curve in the lower portion of the diagram is derived from the upper part by considering the various areas of ductile and brittle failure present in the specimens at each testing temperature. The highest testing temperature at which brittle failure appears in the specimens (*i.e.*, the transition temperature) is T_1, corresponding to the point F_n.

Fig. L—(i) Dependence (assumed) of yield stress YY′ and brittle strength BB′ on testing temperature. (ii) Effect of both strain and testing temperatures on the yield stress YY′Y″ and brittle strength BB′B″. From Y′ to F (corresponding to testing temperatures from T_4 to T_3) the two surfaces intersect; from F to Y″ (*i.e.*, at testing temperatures above T_3) the yield-stress surface terminates without reaching the brittle-strength surface. (iii) Conditions present in the notched-bar test where the yield stress in the specimen varies from Y to Y_n. The YY′Y″ surface is as in (ii), but is not shaded to avoid confusion. The $Y_nY'_nY''_n$ surface intersects the brittle-strength surface from Y'_n (T_3) to F_n (T_1)

The presence of the cleavage facets can be explained either by the relatively slow development of the embrittling change at certain boundaries or by the more favourable orientation of some of the grains for cleavage failure as the crack propagated across the specimen. In the more severely embrittled steel the weakness of the grain boundaries would prevent this from happening. It must be remembered that the theory in Fig. 20 and 21 considers the problem from the macroscopic aspect and does not take into account the micromechanism of fracture.

I do not agree with Mr. Sage that the shapes of the fracture-energy curves for the partially embrittled steels can be explained by a double transition such as he suggests. In Figs. 10 and 11 the curves for the partially embrittled steel are substantially parallel to that for the unembrittled steel (which does not show any intergranular fracture), and in fact it is the latter curve which appears to have the most pronounced change in slope. Such differences in shape between the curves that exist can most probably be accounted for by examining the changing relationships between the slopes of the surfaces in Fig. *L* as the B_1 surface is lowered.

In considering the theory of temper-brittleness it must be borne in mind that, in view of the wide range of elements that give rise to it, there is a strong possibility that several different mechanisms are being loosely classified under the one heading. Of the various elements that are soluble in γ-iron the following give a contracted or closed austenite field in the phase diagram and presumably therefore cannot be easily accommodated in the γ-lattice:

Be, B, Al, Si, P, S, Ti, V, Cr, Ge, As, Zr, Cb, Mo, Sn, Sb, Ta, and W.

The Goldsmidt atomic diameters (for a co-ordination number of 12) for most of these elements, together with that for iron, are as below:

Element	Diameter, Å.	Element	Diameter, Å.	Element	Diameter, Å.
Fe	2·52	Cr	2·57	Sn	3·16
Be	2·25	Ge	2·79	Sb	3·2
Al	2·8	Zr	3·19	Ce	3·64
Ti	2·93	Cb	2·94	Ta	2·94
V	2·71	Mo	2·8	W	2·82

These figures indicate that in most cases the small γ field may be principally due to differences in atomic diameter, although, since Cr is obviously an exception to this, other factors must be important. There will be a tendency for all the atoms that cannot easily be accommodated in the γ-lattice to segregate to the boundaries, and it will be noted that, with the exception of Mn and C, all the elements associated with the occurrence of temper-brittleness are included in the list. Leaving aside those steels which contain high percentages of As, Sb, and P, I would suggest that a plausible mechanism of embrittlement is that indicated by Mr. Sage, *i.e.*, grain-boundary segregation of various elements in the austenite, followed after transformation by the migration of carbon atoms not only to the ferrite boundaries but also to the segregated regions, where they will be anchored by the atoms of the carbide-forming elements. This anchoring of the carbon atoms gives rise to the embrittlement. This hypothesis would predict that Ti, V, Zr, Cb, and Ta steels should also show temper-brittleness. A flaw in the theory is that on the arguments advanced above, Mn would not appear to segregate, and yet Mn steels are very susceptible to temper-brittleness. In those steels where the embrittlement is due to As, Sb, or P, it is, in my opinion, more difficult to provide a satisfactory theory. Atoms of these three elements would appear to segregate to the austenite grain boundaries, and yet, to explain the intergranular embrittlement that develops below 600° C., another process must occur in this temperature range. It does not appear that anchoring of carbon atoms would occur with As, Sb, or P, and so another explanation must be sought. The embrittlement in such steels as Ni–P or Ni–Sb might very likely be entirely the result of segregation in the ferrite of P or Sb, in which case the intergranular facets would correspond to the ferrite grain boundaries and the embrittlement would be independent of the austenite structure. It would be interesting if this point could be checked with the relevant steels.

Mr. Green's theoretical calculation of the plastic constraint factor in the notched-bar impact specimens (presented by Dr. Hundy) is a valuable contribution to the theory of the notched-bar test. It is particularly gratifying to find that the calculated value of Y_n/Y for a 45° notch is 2·35, compared with the assumed value of 2, since the latter was an intuitive guess. Part of Dr. Hundy's question about the theory given in Fig. 20 has already been answered in discussion of the points raised by Mr. Sage, and it is hoped that Fig. *L* will also clarify the position. Briefly, the highest temperature at which brittle fracture appears in the notched-bar specimens will be the highest temperature at which the surface of the maximum yield stress intersects the brittle-strength/strain/temperature surface, *i.e.*, T_1 in the diagram. However, in the notched-bar specimens only a very small region of the bar will have a yield stress of Y_n, and in the remainder of the bar, where the plastic constraint factor is less than the maximum, brittle fracture will not occur until a lower testing temperature than T_1. The yield stress within the bar will vary continuously from Y_n, at some point in the middle of the bar not far below the notch, to Y at the free surfaces of the bar; thus, as the testing temperature is decreased, there will be a continuous increase in the amount of brittle fracture. At a temperature T_a between T_1 and T_3 brittle fracture will occur both over those regions of the bar where the yield stress is greater than the brittle strength B_a, and also over those areas where the yield-stress/strain curves intersect the brittle-strength surface. With decreasing temperatures below T_1 more and more of the cross-section of the bar fulfils one or other of these conditions, until at T_3 the whole bar shows a brittle failure. Essentially, the reason that the fracture-energy/testing-temperature curve gives a transition range instead of a sharp discontinuous break is that the stress system in the bar is not uniform.

In conclusion, it is clear that if the cleavage and intergranular strengths of metals could be directly determined, much of the uncertainty surrounding temper-brittleness and similar problems would disappear. To this end it would be very valuable if a helium cryostat, capable of operation down to about 10° K. in conjunction with a tensile testing machine, could be constructed in this country so that fundamental data on the mechanical properties of metals could be obtained. At least one such apparatus is in existence at the Massachusetts Institute of Technology, and preliminary results[11] indicate the great potentialities of the equipment.

Dr. **R. D. Carter** (in reply): Mr. McLean's reference to our preference for a precipitation theory partly because "one of their steels containing manganese failed to produce an effect with zephiran chloride . . ." is not strictly accurate. Our finding that the picric acid and zephiran–picric reagents detected temper-brittleness in chromium-containing susceptible alloys, but never in susceptible alloys containing no chromium, was observed repeatedly and consistently (except in the susceptible Fe–Cr–As–C alloy 47). We mention five susceptible alloys containing manganese and no chromium (13, 14, 44, 45, and 49); none of these was ever found to give the slightest response to the zephiran etchant, and our

examination of them was by no means casual. Many different etching times and treatments were used, but no trace of the dark-etching structure, so readily found in susceptible chromium-containing alloys, was ever seen in any of them. The nickel–manganese steel of his own investigations, which showed a response to the zephiran etchant, on repeated repolishing and etching, had a chromium content of 0·09%, which is much more than the 0·01% of our own nominally chromium-free alloys, and which seems to account both for the etching response he obtained and for the fact that it was revealed only with difficulty. In our own alloy 58, containing 0·41% of chromium, we detected an etching difference with ease, and we have also found an etching effect in commercial steels, nominally chromium-free, but containing rather more than the 0·01% of our high-purity alloys. Mr. McLean considers that our plain-carbon alloys may have been susceptible to temper-brittleness. Although we did not guard against the possibility of quench ageing, our Fe–C–P and Fe–C alloys (30 and 31) showed no difference in hardness between the 'unembrittled' and 'embrittled' conditions, and there was no trace of the intercrystalline brittle fracture that was associated with the development of temper-brittleness in other materials. Would he have us believe that temper-brittleness did occur in these two alloys, but that its effect on transition temperatures was almost exactly counteracted by a quench-ageing phenomenon, and also that in these two alloys it failed to produce its characteristic intercrystalline brittle fracture? This seems an unlikely combination of circumstances, and we feel justified in accepting our simpler hypothesis. It is hardly reasonable to compare the behaviour of our own alloys, containing 0·10% of carbon, with that of Swedish iron containing 0·015% of carbon.

Our paper has given Mr. Carr the impression that we attribute temper-brittleness mainly to the presence of carbon, but our results did not enable it to be attributed solely, or even mainly, to the presence of any one element. Rather, as Dr. Allen pointed out, we showed the importance of the combination of either chromium or manganese with phosphorus.

We agree with Mr. Sage in attributing some of the scatter in impact-test results to variation in the finish of the notch, although our impact-test specimens were notched carefully in the standard Hounsfield notching machine. He will find our definitions of transition temperature on p. 391 for carbon-containing materials and on p. 395 for the carbon-free materials. Out of more than 200 transition temperatures quoted in our paper, 28 are fully shown and are quite representative; to have shown them all would have occupied four pages of the *Journal*. Temper-brittleness is not capable of the simplified type of explanation that he outlines; should, for instance, one deduce from his table of atomic radii that the effect of nickel is greater than that of phosphorus? Our own experimental results would certainly not bear that out.

Mr. Hopkins is to be congratulated on giving so much minute and critical attention to our paper. I trust he will forgive me for pointing out that the purpose of our studies was primarily to investigate temper-brittleness, and that temper-brittleness is a very definite and distinguishable form of intergranular brittleness with quite specific characteristics. It is not necessarily, or even evidently, connected with intergranular embrittlement by oxygen in carbon-free alloys, with which he is so familiar. The tendency to lump these two forms of intergranular brittleness together is most unfortunate, and is likely to give rise to erroneous generalizations and theories.

Although our alloys were solidified under a residual pressure of less than 0·005 mm., we would not claim that they were oxygen-free; in fact particles of oxide could occasionally be seen in micro-sections. Most of our work, however, was carried out using alloys containing an addition of at least 0·1% of carbon, and intergranular fractures in these were always associated with temper-brittleness caused by the addition of manganese and phosphorus or chromium and phosphorus. We never had any reason to think that the trace of oxygen almost certainly present was having any significant effect under these conditions, any more than the 0·006% sulphur of our basis iron, which was present also in the materials used in his own researches at the N.P.L., and which he appears prepared to ignore. Since our melts, which weighed little more than 1 lb. each, had to suffice for as many as 200 impact tests and for determination of the intentionally added elements, oxygen estimations were not carried out—partly on account of the large sample weights required for accurate determinations and partly because we had no reason to think that oxygen was playing a significant part in the carbon-containing alloys in which we demonstrated the characteristics of temper-brittleness as it is generally recognized. Mr. Hopkins is quite justified in concluding that the introduction of carbon in the solid state counteracts the intercrystalline embrittling effect of oxygen, and this, in fact, is good evidence that temper-brittleness is a different phenomenon.

Our reasons for concluding that temper-brittleness does not occur in the absence of carbon can hardly be enlarged upon; they are essentially

(i) That, in the absence of carbon, embrittling treatments do not give rise to any fall in grain-boundary cohesion, and

(ii) That there is lack of response to etchants when carbon has been removed.

The two non-susceptible alloys of Table VIII (22 and 42) were included in the experiments purely for purposes of comparison, and they were not adduced as proof of the effect of carbon; I am inclined to think that Mr. Hopkins would have complained if two non-susceptible alloys had not been included in this series! We would agree that the mechanism of the etching process is not properly understood, but it was not used as evidence without some consideration of the factors involved. In comparing etching behaviour between carbon-containing and carbon-free materials, we are concerned with the grain–grain-boundary electrochemical difference as it is affected by the removal of carbon. We need consider only carbon in solid solution, for it is not probable that the excess of carbon present as carbide will have any direct effect. The variation in the concentration of carbon in solid solution between carbon-containing and carbon-free alloys, quenched from 500° C., is no more than 0·004%. Among the alloys that showed a definite etching response there is a variation in chromium content of about 2% (40 and 56), in manganese of 1% (40 and 48), and in phosphorus of 0·1% (55 and 61), and all these elements would be present mainly in solid solution in ferrite. That the etch test should break down because of a variation in carbon content of only 0·004%, and yet remain reliable with such greater variations in the concentration of these other elements, may be possible, but does not seem very likely.

Mr. Hopkins's statement that "the apparent increase in susceptibility . . . caused by manganese and chromium may be due to their not being very potent in removing the effects of phosphorus . . ." is not one that we would support at all, and it is not surprising that he "does not understand" the results for the phosphorus-containing alloy (30) with no manganese or chromium. The results we obtained for this material refute his hypothesis, which also conflicts with other experimental observations.

The rise in transition temperature on increasing the degree of temper-embrittlement of a given material merely reflects the continuing fall in intergranular cohesion, and we introduced the idea of modified susceptibility in an attempt to relate these two variables. The assumptions made may be questionable, but they are by no means unreasonable, and a constructive suggestion on this difficult matter would have been welcomed. No one would suggest that a given rise in transition temperature implies the same fall in intergranular cohesion, whatever the range over which the transition temperature rises, and the modified susceptibility was employed in an attempt to assess the susceptibilities of our alloys on a more fundamental basis than the crude measurement of transition-temperature differences. As we state on p. 391, the simple rise in transition temperature is a useful guide to susceptibility. Mr. Hopkins can hardly be hinting that we should have carried out extensive tensile tests at − 196° C.: this would have been quite impracticable in our investigations, which were done on a very modest scale in comparison with those with which he is associated. Nevertheless, tensile tests at − 196° C., although giving a direct measure of the brittle strength of a material under those specific conditions, will eventually have to be related to conditions encountered in the use of steels under practical conditions, and the relationship between brittle-fracture stress and transition temperature in the impact test will then be of considerable importance.

The supplementary details of the three normally susceptible chromium-containing alloys mentioned on p. 396 are as follows:

Alloy No.	Transition Temperature, ° C., and Nature of Brittle Fracture	
	' Unembrittled ' (650° C., 2 hr., W.Q.)	' Embrittled ' (as ' unembrittled ' + 500° C., 120 hr., W.Q.)
55	+ 4	− 16
	Mainly intercrystalline	Mainly intercrystalline
62	− 3	− 31
	Mainly intercrystalline	All cleavage
65	+ 17	− 4
	Mainly intercrystalline	Mainly intercrystalline

All alloys first treated in Anhydrone-dried hydrogen at 950° C. for one week and then at 750° C. for one week, and subsequently heat-treated in the same atmosphere (*see* p. 396 of the paper).

Dr. **A. R. Entwisle** (in reply): Dr. Allen's remarks about temper-brittleness in steel castings are very interesting. Although it has long been suspected that castings are more prone to temper-brittleness than forged materials, there are few data available. It seems likely that the segregations set up on solidification would play a large part in this effect.

Both Mr. Russell's theories seem equally unattractive, the first for the reasons given by Mr. Woodfine. The second theory seems unlikely to be useful, since it cannot explain the very high transition temperatures obtained in the steels containing antimony. Here we have obtained transition temperatures higher than those often obtained in pure iron. This can hardly be due to the removal of solute atoms away from the grain boundaries.

Mr. McLean's contribution is most welcome, and I would agree with him when he describes the etching effects as ' delicate.' The absence of etching at the grain boundaries is not at all conclusive that temper-brittleness is absent, unless the greatest care has been taken with the polishing and etching of the specimen.

The results shown by Mr. Carr in Fig. *C* seem to indicate that the replacement of chromium by nickel decreases the rate of embrittlement but increases the maximum amount obtainable in the steel. This is comparable with the effect of molybdenum additions to susceptible steels noted by many of the earlier German workers, where a great reduction in apparent susceptibility was obtained when the embrittling times were relatively short. For longer embrittling times, however, no real reduction in susceptibility was obtained. This was the phenomenon usually known as ' heat embrittlement ' (Warmerspröding). Although this work was carried out with room-temperature tests, the effect appears to be real.

In regard to the effect of hardness on susceptibility, the results shown in our Fig. 7 cover a rather smaller range of hardness than Mr. Carr's. It seemed necessary to make the distinction between different hardnesses obtained solely by varying the tempering time at a constant temperature and those obtained by varying both tempering temperature and time. In our work we adopted the former procedure, in contrast to Jaffe and Buffum, who used the latter method. The differences between our results and Mr. Carr's seem to arise for the same reason. For the three sets of results in the range 300–380 D.P.N. Mr. Carr used a tempering temperature of 600° C., and for the two sets at 180–220 D.P.N. a tempering temperature of 740° C. (*see* Fig. *D*). There is another possibility; our embrittling treatment was not prolonged (4 hr. at 525° C.), and the discrepancy may have arisen because of the effect of the softening on the initial rate of embrittlement. I think that both sets of results make it clear that from the industrial point of view prolonging the tempering treatment decreases the effects in room-temperature tests.

The results presented by Mr. Carr in Fig. *E* confirm the very great effect of antimony. However, the most interesting feature of these curves is the effect of antimony on the unembrittled transition temperature (full-line curves with open circles).

For the same quenching and tempering cycle we have the following results:

Antimony, %	0·00(?)	0·09	0·02	0·08
Transition temperature, ° C	−30	−25	−25	+30

There seems to be no ready explanation of these results, and I can only suggest that Mr. Carr should examine the fractures of the more brittle specimens to see whether any temper-embrittlement has taken place at the tempering temperature. We found this to be the case with the En 23 steels containing antimony (*see* Table VI). We hope that Mr. Carr will be able to publish a fuller account of his work in the near future.

Mr. Sage seems to paint too gloomy a picture of impact testing:

(i) The ' notoriously wide scatter to be found in impact tests ' seems in part to be associated with the quality of the material tested. For commercial steels, the widest scattering appears to be associated with those having very sharp transitions from tough to brittle behaviour. With the alloy steels dealt with in this work, where particular care was taken with the manufacture and heat-treatment, and where the transitions were less pronounced than in plain-carbon steels (not quenched and tempered), the scatter was found to be rather less. Figure *M* shows four curves typical of tests carried out in this laboratory. The corresponding transition temperatures are to be found in Table IV of our paper. We have not ' been satisfied to base our work on single impact tests at a given temperature.' The tests were concentrated on the temperature range of interest, *i.e.*, the upper part of the transition range. By drawing a curve through the experimental points, an averaging is obtained and the transition temperature is determined.

(ii) The machining of the specimens used in our work was carried out by myself. The actual machining and subsequent inspection was carried out sufficiently carefully to ensure that the specimens were of a uniform size

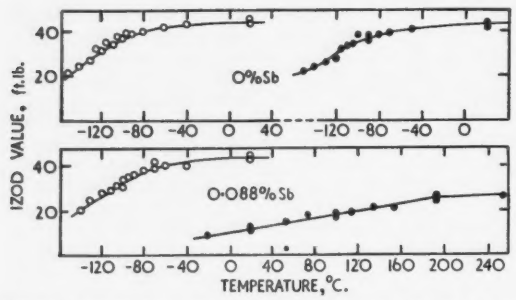


Fig. M—Typical tensile-test results on steel En 23 + Mo

and shape, corresponding to the British Standard Specification. A careful check was kept on the notch cutter, particularly on the profile at the root of the notch, and a cutter was discarded when any significant signs of wear were noticed.

The results quoted by Mr. Sage give an unrealistic view on this question of machining, since he gives no information on the quality, composition, and heat-treatment of the steel used, nor on the testing conditions. The impression these results give is that the steel he used was a poor-quality low-carbon steel, in which some segregation was present. This would give rise to the scatter in the two series of tests. The difference between the two series could easily arise if the transition temperature of the steel was in the region of room temperature (this is very likely if our initial deductions are correct). I would then suggest that the two series were tested at different times when the ambient temperatures were different.

Thus it is seen that the scatter may arise from three distinct sources:

(*a*) Inhomogeneity of the material
(*b*) Lack of precision and uniformity in machining
(*c*) Inadequate control of testing conditions.

(iii) I do not consider that the alternative transition curves Mr. Sage would draw would impair the validity of the conclusions to be drawn from these papers. The fact that no transition curves are reproduced in our paper is the result of an attempt to conform with the 'Notes to Authors' contained in former issues of the *Journal*. I do not believe that the reproduction of a large number of transition curves, on a scale sufficiently large to be of value, would merit the space occupied by them.

(iv) I agree that our definition of transition temperature is somewhat arbitrary, but at the time the work was carried out I felt that it was less liable to subjective errors than Woodfine's. A further consideration of this has led me to the conclusion that the criterion proposed by Jaffe and Buffum may be somewhat superior. They measure the percentage of fibrous fracture in the broken specimens and plot this against the testing temperature. From the curve drawn through these points, they find the lowest temperature on the curve corresponding to 100% fibrous fracture. This point corresponds to a small drop in energy absorption of up to 25%, so that, even here, the slope of the transition curve is involved.

If, however, the determination of transition curves becomes more general (as seems likely), the adoption of some arbitrary drop in impact value would seem a more workable criterion despite any theoretical advantages. The practical disadvantage is, as Mr. Sage points out, the effect of the slope of the transition curve. By taking the arbitrary drop in impact value sufficiently small, this effect can be kept small.

The problem of which factors influence the shape of transition curves is a pressing one. Until we have more information on this matter, we are precluded from making any simple specifications of the type: 'The impact value shall not fall by more than 25% when the testing temperature in the impact test is lowered from + 20° C. to (say) − 20° C.' for materials which might be prone to notch brittleness in service.

Mr. Hopkins suggests a connection between temper-brittleness and the intergranular brittleness caused by phosphorus in pure iron. A critical experiment that might throw some light on this matter would be to determine the path of the brittle fracture in specimens of a susceptible alloy steel that had been tempered at a very high temperature for a long period. If complete spheroidization had taken place, the ferrite grain size would perhaps approach that in Mr. Hopkins' alloys, and the ferrite boundaries might not have any relation to the previous austenitic grains. If the fracture was round the ferrite grains, some connection would be indicated.

Mr. Burns' remarks about the radial cracking observed in tensile fractures are very pertinent. The precise reason for this type of failure seems to be quite obscure. The effect must be connected with the high degree of cold work or the stress system in the neck of the specimen. This is easily proved by testing similar materials at low temperatures, where the reduction in area is less. The radial cracking is then absent.

The effect of size of section may be due to the influence of the hot-working the steel has had, giving rise to directional properties. I should be very interested to hear if Mr. Burns has noticed this effect of section on test pieces of different diameters cut from a single bar (cut both before and after heat-treatment). Any data on this point might help us to decide whether it is the heat-treatment or the initial structure of the material that is important.

I agree with Mr. Burns that any direct connection between this type of failure and temper-brittleness is rather tenuous.

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IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP

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REPORT OF THE TWENTY-FIRST MEETING

THE TWENTY-FIRST MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held jointly with the Plant Engineering and Steelmaking Divisions of the British Iron and Steel Research Association on Wednesday, 21st January, 1953, at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

At the MORNING SESSION the two papers "Cold-Metal Practice: Fixed 80–100-Ton Furnaces," by J. E. PLUCK (Steel Peech and Tozer), and "Hot-Metal Practice: 80-Ton Fixed and 250-Ton Tilting Furnaces," by S. G. WILLIAMS (Guest Keen Baldwins Iron and Steel Co., Ltd.), were presented and discussed. Mr. J. F. R. JONES, Chairman of the Plant Engineering Divisional Panel, occupied the Chair.

Summaries of the papers and the discussion will appear in the September issue of the *Journal* (Vol. 175).

At the AFTERNOON SESSION Dr. T. P. Colclough, C.B.E., Chairman of the Steelmaking Divisional Panel, was in the Chair. Summaries of the two papers presented and the discussion are printed below.

PROCEEDINGS OF THE AFTERNOON SESSION: 1.30 P.M. TO 4.0 P.M.

Repair and Maintenance of Open-Hearth Furnaces in Germany

By A. Mund and C. Kreutzer

THIS paper reviews briefly the methods used in Germany to develop the open-hearth furnace to its highest efficiency and durability. Conditions in German open-hearth steelworks are very different from those in the U.S.A. For example, in America wages are higher and the cost of materials is much lower than in Germany. The large-scale layout of the steelworks permits the use of heavy machinery and conveyor belts, and most of the refractory bricks are laid dry. Hence, repair times are short and a high degree of utilization is reached. In Germany, many of the works are old, restricted, and inconvenient in layout, and the extensive use of auxiliary equipment is impossible.

It has therefore been necessary to approach the problem differently and to increase as far as possible the durability, thus reducing the number and duration of furnace repairs. In this way, a degree of utilization at least as high as in America, and sometimes higher, is achieved. Furthermore, the various fields of furnace design, furnace control, measuring and observation, scrap economy, and transportation are being co-ordinated to achieve the highest possible output of steel.

In Western Germany 52·5% of the total steel output is produced by the open-hearth process. At

A shortened version of the paper presented at the Twenty-First Meeting of the Iron and Steel Engineers Group, held jointly with the Plant Engineering and Steelmaking Divisions of the British Iron and Steel Research Association, on Wednesday, 21st January, 1953, at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

Dr. Ing. Mund and Dr. Ing. Kreutzer are at Maerz Ofenbau G.m.b.H., Krefeld, Germany.

present 194 open-hearth furnaces are in operation, of which 29 (14%) are tilting furnaces. About half of these are fired with a two-gas mixture, and the remainder with a three-gas mixture. Of the 165 fixed furnaces, 58 are coke-oven-gas fired; 40 of these (70%) are oil-carburetted. Oil-carburetting is being increasingly used, although no furnace is yet completely oil-fired. There are 107 fixed furnaces fired with producer gas and mixed gas; about 40% are pure producer-gas fired, 30% two-gas, and 30% three-gas.

The proportion of hot metal in the fixed, producer-gas, and mixed-gas fired furnaces varies between 20 and 40%, and in the tilting furnace it may be as high as 70%. Of the coke-oven-gas fired furnaces 55% are charged with hot metal.

The overall average tapping capacity is 70 tons, the averages of each type being as follows:

Fixed producer-gas and mixed-gas furnaces: 58 tons
Tilting furnaces: 150 tons
Coke-oven-gas furnaces: 50 tons.

OPERATIONAL DETAILS

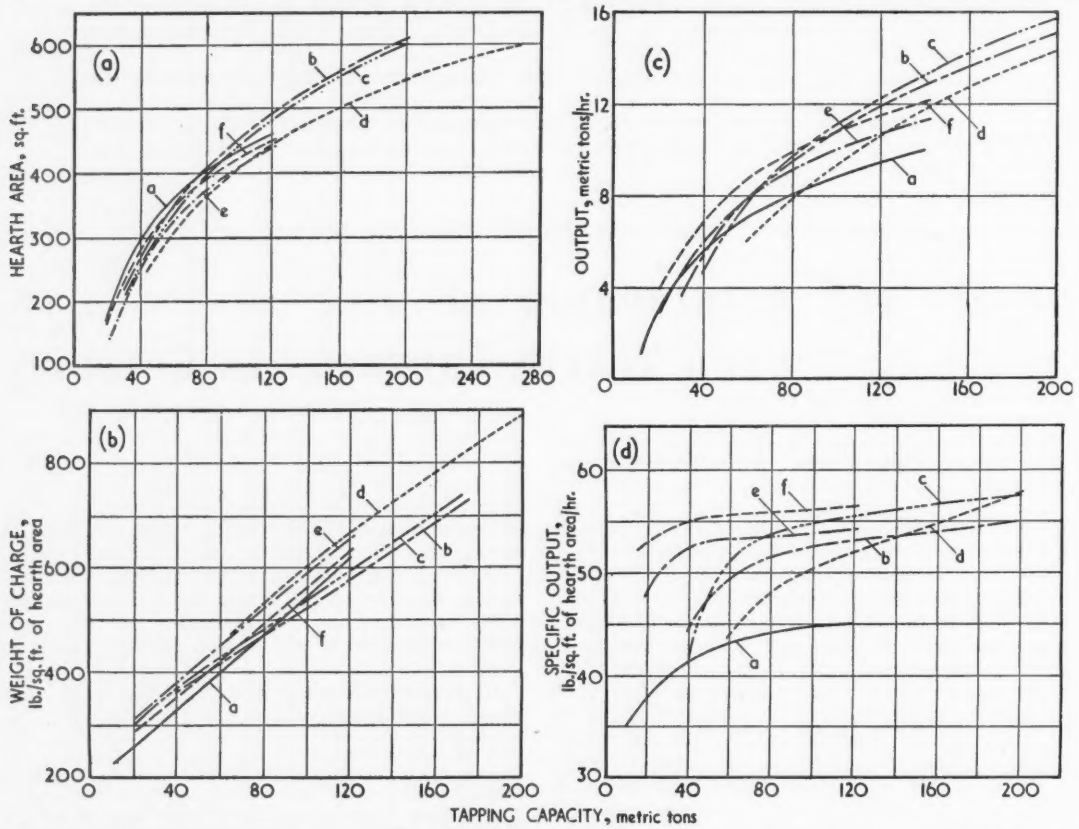
Factors Affecting Output

Figures 1*a–d* show the standard curves for useful hearth area, weight of charge per unit of hearth area, output per hour of various furnace groups, and specific output, plotted against tapping capacity. As a rule, the individual outputs of the furnaces can be up to 20% higher than the values indicated by the standard curves, under particularly favourable working conditions, *viz.*, short charging times with a high proportion of workshop scrap, a favourable production programme, and good furnace maintenance and control. As the curves represent average values, some of the furnaces have poorer performances.

In Fig. 1*d*, the specific output, *i.e.*, the output per hour per unit area of the hearth, of a 60-ton furnace, for instance, is approximately 43 lb./sq. ft./hr. with producer-gas firing, and 56 lb./sq. ft./hr. with coke-oven-gas firing and a hot-metal charge, *i.e.*, 30% lower. Figure 1*d* also shows that by increasing the furnace size above a certain limit, irrespective of the kind of firing, there is only a very slow increase in the specific output. This means that the hearth area is the only criterion for the output per hour.

This is significant for the design of the furnaces, especially as the smaller furnace is not so economical. The expenditure of heat increases as the ratio of the effective hearth area to the brick volume of ports, checkers, roof, walls, etc., which must be kept at a peak temperature, becomes increasingly unfavourable.

In contrast to the other furnace types, the tilting furnaces show a substantial rise in specific output as



a—Producer gas, solid charge for fixed furnaces
b—Mixed gas, solid charge for fixed furnaces
c—Mixed gas, liquid charge for fixed furnaces
d—Mixed gas, liquid charge for tilting furnaces
e—Coke-oven gas, solid charge for fixed furnaces
f—Coke-oven gas, liquid charge for fixed furnaces

Fig. 1—Standard curves of (*a*) hearth area, (*b*) weight of charge, (*c*) output, and (*d*) specific output, related to tapping capacity

the size of the furnace increases. This is explained by the fact that the German tilting furnaces have a hearth area per unit charge considerably lower than the average. The charge weight per unit of hearth area can be increased considerably above the nominal capacity of the furnace, with a simultaneous increase in the specific output. A mixed-gas hot-metal furnace, with a capacity of 60 tons, was, without any special structural alterations, charged with 90 tons.

To summarize, by departing from the standard curves, a higher output than normal, both absolute and per square foot of hearth area, can be achieved only by special measures; these include the kind of firing adopted, port design, position and shape of the flame, the degree of air preheated and of chimney draught, scrap preparation, and charging time. Of the greatest importance is the influence of the proper heat input, *i.e.*, the provision of an adequate quantity of heat while charging and melting the scrap.

Scrap Preparation and Charging

One of the most important factors influencing performance is charging time, which is determined by the preparation of the scrap. Most German steelworks are trying to increase the charging performance per hour. Good results have been obtained by using larger charging-boxes and loading them in scrapyards at some distance from the steelworks. At smaller works, charging-box carriers, capable of taking eight or twelve boxes, travel between the scrapyard alongside the furnace bay and the stage. Each load of boxes is weighed as a whole.

A method of charging that is under development involves a fixed, non-rotating charging machine on rails. It has a plunger instead of a bolt lever. A special charging-box, with a capacity of 5 cu. m., is loaded in the scrapyard; a crane puts it on the machine, which advances and pushes the box into the furnace door. The plunger then presses the scrap slowly into the furnace. When it has moved right up, the empty box is pulled back, the plunger remaining in position. In this way the rest of the scrap is put into the furnace; the box and plunger then move back, and the furnace door is closed.

With this equipment it should be possible to charge a 60-ton heat in nine sets, *i.e.*, three for each furnace door. With the ordinary method each door must be opened at least 20–25 times. The heat lost during charging should thus be reduced very substantially and the melting performance correspondingly increased.

In Germany, scrap now undergoes more intensive preparation than in the past, *viz.*, by pressing into bales or by cutting with scrap shears or torch. Owing to the increasing shortage of scrap the general trend is towards the pig and ore process. Occasionally, as much as 40–55% of hot metal is charged.

A further improvement in performance is expected from the introduction of the hot-blast cupola furnace for the premelting of scrap, with the possible addition of ores. This process enables an inferior charge of scrap bales or short-cut scrap to be preheated with an extremely low fuel consumption. At the same time an analysis of the premelted iron is adjusted so as to be as favourable as possible for the open-hearth furnace. Calculations have shown that a 50–60% improvement can be achieved in the output of the furnace.

Use of Oxygen

Economic success has been achieved in the enrichment of air to 23% in gas producers; in speeding up scrap melting by enrichment of combustion air to 23–24%; in decarburizing by lance in certain cases, such as the production of very low carbon steels; and in desiliconizing stahleisen by oxygen injection in the ladle.

Instrumentation and Automatic Control

The performance and life of the open-hearth furnace can be improved by careful control by means of instruments. The chief applications are:

(1) To maintain similar temperature and draught conditions at both ends of the furnace
(2) To keep the roof and checker temperatures at the highest possible limit
(3) To obtain correct combustion conditions
(4) To regulate the quantity of fuel with the progress of the heat; *i.e.*, to control the heat input on the basis of reliable temperature measurements of the bath and analysis of the steel.

The element of human control should not be entirely eliminated. Automatic instruments are very sensitive and considerable risk is involved in employing fully automatic control for reversing the furnace. However, trials have been made on automatic regulation of the ratio between coke-oven gas and/or oil and the required combustion air.

In general, it is best to register only a few measurements, but these should be carried out with great accuracy and care. This will ensure longer lives of roof and chamber.

Improvements in Firing and Carburetting

Apart from the increasing use of coke-oven gas carburetted with oil, oil of various origins, sometimes with pitch–creosote additions, has been used more and more in mixed-gas furnaces. The addition of oil increases furnace performance, reduces gas consumption, and reduces the time off for repairs.

An important feature in firing and carburetting coke-oven-gas and mixed-gas and/or producer-gas furnaces is the development of gas and oil burners, the aim being to be able to influence the shape of the flame at will. The gas burners have an outlet of oval cross-section to produce a good covering gas flame. The delivery speed of the gas, which depends on the available gas pressure in the mains, is an important factor.

With lignite-dust carburetting, the dust, conveyed by compressed air from the bunker to the furnace, is fed to the gas burner at a certain distance from its outlet so that it can mix intimately with the gas flow. In some furnaces it can also be fed to the furnace by separate dust nozzles, either below the gas burners or through the monkey walls.

The coke-oven-gas furnaces have one, two, or three gas and oil burners on each side of the furnace. The three-burner furnaces all give the highest performance.

Oil-carburetting has been intensively developed. Oil from pit coal or lignite tar with a certain proportion of pitch, mineral oils, such as residues from refineries, or crude oils are suitable. Atomizing with

steam and/or compressed air, with neutral blast-furnace gas at 6–8 atm., is applied in mixed-gas furnaces where the oil is added in the gas port.

Good atomizing, and hence rapid combustion, enable the more highly sulphurous mineral oils to be used. To obtain a long flame during refining, the burners are often pushed in the furnace up to the bridge bank.

MAINTENANCE AND REPAIRS

Types of Furnace

The Maerz furnace was developed to simplify the lining of the port end and to improve accessibility to individual furnace parts for repairs during normal operation. This was achieved by making it possible to remove or interchange single parts of the port end. At present there are 26 Maerz furnaces in operation in Western Germany.

The favourable output of the Maerz furnace is due to its sharp flame, which guarantees rapid melting of the charge. A further advantage is the durability of the ramp roof as a result of the flow of the flue gas and/or air. There is very little wear on the roof at that point, as the flue gases flow at a very great distance from the ramp roof into the air and gas uptakes, while the ascending air is diverted by the ramp roof, which is actually cooled and therefore has an unusually long life.

There are only a few Venturi-type fixed furnaces in operation in Germany. All the other furnaces, including the majority of the fixed furnaces, have the usual Siemens ports or in some cases the removable Friedrich ports. These ports must therefore be basic-lined. This lining is more difficult to carry out than that of the normal Siemens ports, as the relevant parts of the ports are practically inaccessible for hot repairs.

Interchangeable ports are convenient, but the steel-works must have a stockyard capable of housing the spares and a crane installation above the furnaces with a carrying capacity of up to perhaps 80 tons. The proper adjustment of the ports is not always easy, however, and even a slight maladjustment may result in a change of the flame position and in undesirable wear of the brickwork.

The quantity of brick in a Friedrich port is 40% higher than that in a Maerz port.

Cooling

Basic-lined door jambs are being fitted to an increasing extent with cooling pipes built in at two or three different levels of the front wall, with excellent results. In addition, plates are frequently inserted between single horizontal brick courses in the front wall, usually at intervals of four brick courses. They are supported by the furnace steelwork, but can move in a vertical direction.

Water-cooling is also applied at the junction of the air and gas uptakes in the port in Maerz furnaces and in the gas port of normal open-hearth furnaces. The bridge banks and the walls of the air uptakes, especially in coke-oven-gas furnaces, are also cooled by pipes or inserted flat boxes. In some cases, the upper part of the back walls and the skewback channels over the front walls of basic-lined furnaces are also cooled.

The most modern door frames are cooled with low- or high-pressure steam. This results in large economies in water, and the steam produced can be used for other purposes.

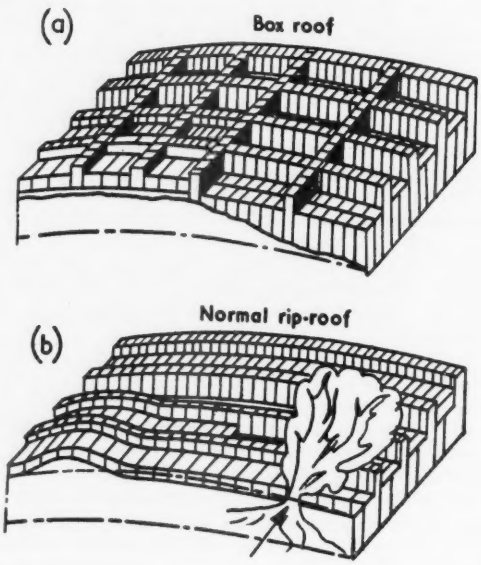
Roof Life

The life of the main roof determines the length of the campaign. Supported and suspended basic roofs, and with them all-basic open-hearth furnaces, are being more and more widely used. At present, 30% of the furnaces have basic roofs.

In individual cases extraordinarily long roof lives have been achieved; in a large coke-oven-gas furnace with additional oil firing, the roof lasted approximately 1750 heats, producing 192,000 tons of steel. A coal-dust-carburetted, 60-ton, coke-oven-gas furnace produced more than 100,000 tons of steel with one roof lining. At the end of December, 1952, a 35-ton coke-oven-gas furnace roof had attained the unique life of 4000 heats, that is, about 23,000 hr. under fire. With such lives, repairs are no longer important, especially as the linings of the front wall, back wall, end wall, and checkerwork lasted 12–18 months without any delay for repairs.

Although these high durabilities are not achieved with producer-gas and mixed-gas furnaces, a number of campaigns have reached 12–18 months. The good results are achieved by careful bricklaying in the roof, working with only a slight pressure of the roof springs, and by inserting filler bricks between the ribs.

A further improvement in the life of the roof, especially of silica-ribbed roofs and also of basic, suspended, ribbed roofs, can be obtained with the box roof (Fig. 2). The single courses between the lateral ribs are subdivided by the insertion of longitudinal ribs into any desired number of fields, called



(*a*) *Box Roof*
Some boxes with filler bricks; roof not buckled and not burnt through

(*b*) *Normal Rib Roof*
Ribs with filler bricks; roof buckled and burnt through

Fig. 2—Comparison of normal rib roof with box roof

boxes. This provides a further bracing of the whole roof and also enables any single prematurely worn places to be secured by filling up the affected boxes with filler bricks. Without this box division the whole course must be relaid from the back-wall skewback to the front-wall skewback, since if only the thin place over the back wall, for instance, were filled up, the course behind the last filler brick would burn through. At the prematurely worn places the boxes are filled up with filler bricks, using a mortar that sinters at low temperatures with a high refractoriness. After a few hours these bricks are sintered with the last part of the original roof course and also with the rib bricks between which they are loosely inserted. By this process the life of the roofs can be lengthened by at least 25–50%.

Ribbed and box roofs, acid- and basic-lined, are frequently cooled by forced draught. A suitable pipe network is laid over the whole roof. The connections between various sections can be opened or closed as required. This air-cooling also lengthens the roof life, even before the courses and/or boxes are refilled.

Checker-Chambers, Flues, etc.

To give a good dispersion of the waste gas and air, respectively, over the checkerwork, particularly in the air chambers, the most modern design provides for very slender chambers; the horizontal cross-section of the chambers is as small as possible and nearly square. The overall height, and hence the height of the checkerwork, is considerable. This, however, requires the chambers to be laid in an insulated concrete foundation tank as, in most cases, the bottom lies below the underground water level. The checker passages widen from top to bottom to prevent premature clogging of the checkers. Particles of slag and dust which accumulate and then detach themselves can thus drop through to the flues under the checkerwork. These flues must be cleaned out at intervals of 4–5 months. By the introduction of additional (unburned) gas to the flue gases, with an intentional feed of infiltrated air, delayed combustion results in the checker-chambers. If this process is continued for 1–2 hr., the checkerwork is intermittently overheated and the chambers are cleaned ' by melting,' while most of the dust deposits drop into the flues.

In another method the checkerwork is accessible for cleaning through the side and front walls of the chambers. With the aid of a bent compressed-air nozzle, all the passages of the chambers can be blown clean through a number of openings which are walled up during furnace operation. This is carried out fortnightly.

In furnaces with heavy waste-gas dust deposits, *e.g.*, in furnaces fired by coke-oven gas, carburetted with lignite powder, or fired with a large oil addition, the greatest attention must be paid to these flues. As soon as the dust and slag deposits exceed a certain amount, a bottleneck is formed in the flues and must be eliminated in good time. A deep observation shaft is therefore built outside the waste-gas flues to allow better observation below the checkerwork.

The slag pockets are as large as possible. Recently, the trend has been to follow the American example and, in the case of an all-basic furnace, the air uptakes and the roof and walls of the slag pockets are basic-lined. The slag produced is loose and granular and can be quickly removed with mechanical shovels; explosives and heavy breaker equipment are not required.

It is hoped to further improve the openings of the air-uptake junctions in the roof of the slag pockets by suspending them by metal-cased chrome-magnesite or magnesite-chrome bricks, thus providing every desired shape of roof, including a horizontal suspended roof.

In heavy-duty open-hearth furnaces the checkerwork is of fireclay bricks, the quality of the bricks increasing from the lower to the upper courses. The top 6–8 courses are packed with high-alumina checker bricks, good results being obtained, especially with thick square cross-sections. Silica bricks are not sufficiently heat-resistant, particularly if the waste-gas dust is basic. In furnaces exposed to less heavy strain, however, silica bricks are packed on top of the lower fireclay brick courses.

Repair Times

Repair times are undertaken partly with the aid of mechanical transport facilities. Favourable times from the tapping of the last charge until the recharging of the first heat after the repair are:

Coke-oven-gas firing: 8–10 days
Mixed-gas firing: 14–16 days.

These times include cooling down, breaking up, cleaning of slag pockets and checkerwork, bricklaying, and warming up. To speed up the repairs to checkerwork one part of the chamber roof can be taken out. The part of the stage over this opening in the checker roof is also removable, so that the debris can be removed by means of transport boxes.

The indirect or direct artificial downdraught helps to cool the furnace very quickly, and an additional gas pipe simultaneously warms up the furnace.

Fettling is carried out with a centrifugal machine for a special spraying mass of refractory material on a dolomite–magnesite basis, similar to the American ' gun-mix.'

Special Refractory Materials

Development lies clearly in the direction of the high-duty furnace, which goes to the extreme possible limit in its operational temperatures. This has naturally required special refractories. With roof temperatures 250° F. higher than the best silica bricks will stand, the walls and roofs of the regenerator chambers, as well as the checker bricks, are heated up to 2650° F., and partly even higher, to achieve the highest possible air-preheat, even above 2330° F. In furnaces of this description, mainly coke-oven-gas furnaces, the top courses of the checkerwork are of special high-alumina bricks with more than 50% of Al_2O_3. These bricks must be used at these high temperatures or dust settles on them and the checkers become clogged.

The parts that are chiefly liable to wear by the flame and the hot waste gases are normally the port ends, particularly the arch between the gas port and the air port, the throat walls, and, especially in single-uptake furnaces, the end walls and the air uptakes leading to the slag pockets.

Repair and Maintenance of Open-Hearth Furnaces in U.S.A.

By R. W. Evans, M.Met., and I. S. Scott-Maxwell, A.M.I.E.E., A.M.I.Mech.E.

THE average capacity of American steelworks in 1950 was 665,000 tons per annum, and there were 11 works with between 2 million and 6 million tons of annual output. This single factor of size has an important bearing on furnace availability. Large concentrations of labour can be brought to bear at any particular place, and more space is available in and around the plant for mechanical aids to quick repairs.

There are about 900 open-hearth furnaces in America; of these, about 720, or approximately 75%, are fixed, hot-metal furnaces. Since these units form such a large proportion of the total, this paper deals mainly with this type.

The average tapping capacity of these furnaces is 130 tons; about 23% are between 160 and 250 tons. The British average is 90 tons, with about 15% in the range 160–200 tons.

The number of taps per week does not differ much from British practice, but because of the greater tonnage tapped and the higher availability of the furnaces, the productivity per unit of plant averages 50% greater than in Britain. Much of this is due to the very high furnace availability, the national average being 91%, while some works attain 96–97%. Thus, any one furnace is off production for a total of only about two weeks per year.

In Britain, the national average availability is about 80%. Many British works have a 'spare' furnace, which is not normally manned and on which repairs are carried out at a slower pace. This gives a lower availability figure, and it is doubtful whether this practice is now economic in view of the capital cost of new equipment.

National statistics* for basic open-hearth steelmaking, for 1950, for both Britain and America show that an increase of 6% in the average availability of British furnaces would have given an additional one million tons of steel per annum from existing plant, bringing the national availability to 86%.

FURNACE DESIGN AND OPERATION

More than 90% of American open-hearth steel is made with rich industrial fuels—natural gas (sometimes used at the full calorific value of 1020 B.Th.U./cu. ft. and sometimes diluted with air to about 550 B.Th.U./cu. ft.), low-sulphur fuel oil, coke-oven gas, tar, and pitch-creosote.

Most American shops have ground-type, non-slewing, charging machines. The size of the furnaces permits the use of large charging boxes, sometimes of more than 40 cu. ft. capacity. Scrap preparation and a higher grade of purchased scrap give bulk densities of 75–150 lb./cu. ft. of pan capacity. High rates of charging are thereby attained.

In general, a higher proportion of hot metal is used. Basic iron is of excellent quality, being low in sulphur and phosphorus. As a result, slag weights are low compared with those in Britain.

Many design features have changed over recent years, reflecting the continuous effort to attain increasingly higher production from existing plant. The enlargement of uptake areas has reduced wear by reducing gas velocity, in spite of increasing gas volumes due to higher driving rates. Basic ends have been tried, and when these originally gave trouble a suspended design was evolved. Metal-cased magnesite brick has helped lining life, and water-cooling is used extensively on buckstays and, in many plants, on the front and sometimes on the back skewbacks.

Brick door arches have been discarded in favour of the water-cooled archless door frame, which gives a few more production hours each week. With wider aperture checkers and larger slag pockets, checker lives are measured in years rather than months.

American furnaces are designed for and are operated at high rates of heat input, and little thought is given to reducing this or to more careful charging. As a result, 'unit roof-life' is short by British standards. The roof of the furnace has remained a challenge. American furnaces generally have thicker roofs and along the back skewback super-silica brick is used. Although these features help to increase roof life, the roof remains the key to the length of a campaign.

* Productivity Team Report, "Iron and Steel," Table 18, p. 39: 1952, London, Anglo-American Council on Productivity.

A shortened version of the paper presented at the Twenty-First Meeting of the Iron and Steel Engineers Group, held jointly with the Plant Engineering and Steelmaking Divisions of the British Iron and Steel Research Association, on Wednesday, 21st January, 1953, at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

Mr. Evans and Mr. Scott-Maxwell are at the Abbey Works of the Steel Company of Wales, Ltd.

This problem has been answered largely by expert patching. The following figures are averages for two shops of a Chicago works for one year:

	No. 2 Shop: 14 Furnaces of 110 tons (net)	No. 4 Shop: 14 Furnaces of 200 tons (net)
Heats to first patch	133	107
Heats between patches	73	59
Total heats on roof	419	405
Area replaced by patching, sq. ft.	1402	1927
% of original roof put on as patches	187	153
No. of patches per campaign	4·5	6·1

A large percentage of the original roof has thus been replaced by patching during the campaign. These patches, whether large or small, are always effected with great speed. A length of crown 50 ft. long by 3 ft. wide can be replaced in 4 hr.

The additional output achieved by hard driving more than offsets the increased use of refractories. In fact, on large-capacity furnaces the consumption of refractories per ton of output is much lower than on smaller furnaces driven at a slower rate.

ATTITUDE TO FURNACE REPAIRS

The tremendous expansion of steel production in the United States since 1939 is a measure of the extreme and unbroken demand for steel. The yearly production of a plant is the main yardstick by which progress is measured. Once the maximum rate of drive of the furnace is achieved, the only remaining way of increasing the annual production is to keep the furnace in operation for as many weeks as possible. It is realized that maximum rate of drive can be achieved only by keeping the roof temperature at its maximum for as much of the tap-to-tap period as possible. This applies particularly to the charging and melting periods, when high rates of fuel input are maintained in an effort to keep up the roof temperature, in spite of the almost continuous additions of heat-absorbing cold scrap.

Although such treatment results in a shorter roof life, the driving rate is still maintained. The attitude of the operator to the mason superintendent is: " I have burned the furnace down; now you build it up." The furnace is then rebuilt, by using a large labour force and mechanical aids, and is back again in operation after being off for a very short time.

The secret of success is the co-operative planning between the production personnel and the mason's department, and between the mason's department and all the other trades involved, such as fitters, riggers, and electricians. Without a combined effort high availabilities are not possible. Each man understands fully that an open-hearth furnace is a money-making unit for the company and for himself and his family. The production men are just as interested as are those actually engaged on the repair.

The American attitude is: " Get the maximum tons per hour, irrespective of furnace life; that is the first essential: Then, having burned down the furnace quickly, let there be *no* limit to the speed of rebuilding."

BASIS OF AVAILABILITY

The availability figures are calculated (in the simplest case) as the number of hours that the furnace is in production, expressed as a percentage of the total number of hours in the year. The method of measurement varies slightly in different parts of America, but generally if a furnace is patched from the outside, *i.e.*, it is not cooled down sufficiently for men to go inside, then that time counts as production time. If it is cooled down to allow men to go inside, then the furnace is out of production. Off-production periods are computed in hours, and the availability for the whole shop is calculated. The same calculation can be used for multiple shops in an integrated plant. At Sparrows Point the three shops consist of:

	No. 1 Shop	No. 2 Shop	No. 3 Shop
No. of furnaces	12	5	11
Capacity, net tons	166	186	200

For 1950 the average availability for the three shops was 97½%, which means that each of the 28 furnaces operated for 50·7 weeks out of 52. The furnaces are off production for an average of only nine days in the year, and their production in tons/hr. is as high as any in America. The No. 2 shop at Inland has averaged more than 23 furnaces in production out of 24 built, or 96% availability. During a visit to this shop in late 1947, 24 out of 24 furnaces were operating. In 1950 Weirton averaged 95·62% availability. The national average for America of 91% means 33 days off production in the year.

It is doubtful whether any shop or group of shops in America sets itself a target of availability. Rather, repair times are reduced to the absolute minimum, and that is considered to be the best that can be achieved.

If British figures are to be improved, consideration must be given to design, operation, and maintenance. The whole structure and background of the British industry is very different from that of the American industry. For instance, all American figures are based on 21 shifts, whereas some shops in Britain work only 19, thus losing about 10% availability. Perhaps because of shortage of raw materials and the practice of ' spare ' furnaces, roof temperatures in Britain are not so near the critical point as they are in America. Why should there be this fear of burning roofs down ? Why cannot roofs be patched quickly to maintain production ? That is not affected by shop layout or furnace size.

Few British melting shops are designed on the American scale, which permits the use of so many mechanical aids. However, in some new shops at least 90% availability should be possible. This would give a schedule based on each furnace in the shop, or group of shops, working 47 weeks out of 52, which allows 35 days per annum for repairs, allocated as follows:

Two general repairs at 9 days	=	18
Plus two warming-up periods at 2 days	=	4
		22
Two part repairs at 5 days	=	10
Plus two warming-up periods at 1½ days	=	3
		13
Total	=	35 days

This target is very modest compared with those of the best American shops, but it is probably far above

the capabilities of some of the older British plants.

The following factors appear to be necessary to reach this target:

(*a*) All shops to work more than 19 shifts per week, and if possible 21 shifts
(*b*) 'Spare' furnaces should be forgotten and all such furnaces should be manned when raw materials are available
(*c*) Quick patching technique or roof repairs to be adopted, together with higher operating temperatures
(*d*) Better scrap preparation
(*e*) Development of mechanical aids suitable for British melting shops, such as light-alloy roof centres, hanging platforms, brick elevators, and palletization
(*f*) Quicker methods of slag removal
(*g*) Heavier furnace steelwork, additional water-cooling, and quicker methods of wrecking the furnace.

FURNACE REPAIR METHODS

In America, concurrently with improvements in furnace design, methods have been devised for speeding up so that a top repair, including a complete roof, front and back linings, uptakes, and blocks, can be carried out in 21 hr. from 'fuel off' to 'fuel on.'

The repair organization may be conveniently broken down into the following sections:

Job Planning

Generally, a schedule is drawn up for the whole plant, indicating the number of part repairs and general repairs for each furnace during the year. This is necessary in any shop, but particularly where a very large number of furnaces are involved. The schedule must be adhered to as closely as possible so as to avoid bunching the repair periods. Soaking pits and reheating furnaces should be included.

In America, the mason superintendent is responsible for the repair. He determines, with the shop superintendent, when the furnace should go off, and he controls electricians, etc., as well as his own men. In many shops fast repairs are a routine matter, but this has only been arrived at over many years of trial and experience based on detailed planning. The main essential now is to plan and organize repairs in relation to the other furnaces in the shop. All production men are keenly interested in the repairs, and cranemen and machine men are willing to help; nevertheless, production must not be slowed down by repairs on one particular furnace.

At Sparrows Point a tentative schedule is made for six months, on which each of the 28 furnaces appears twice, for either a general or a quick top repair. The schedule of availability is based on 17 heats per week per furnace; a general repair takes about four days and a quick roof repair about 25 hr. When planning a repair three factors are taken into account:

(1) The work on the previous repair
(2) How the furnace operated
(3) The visual state of the furnace.

Each week all foremen and officials concerned meet to plan the repairs scheduled for the following week.

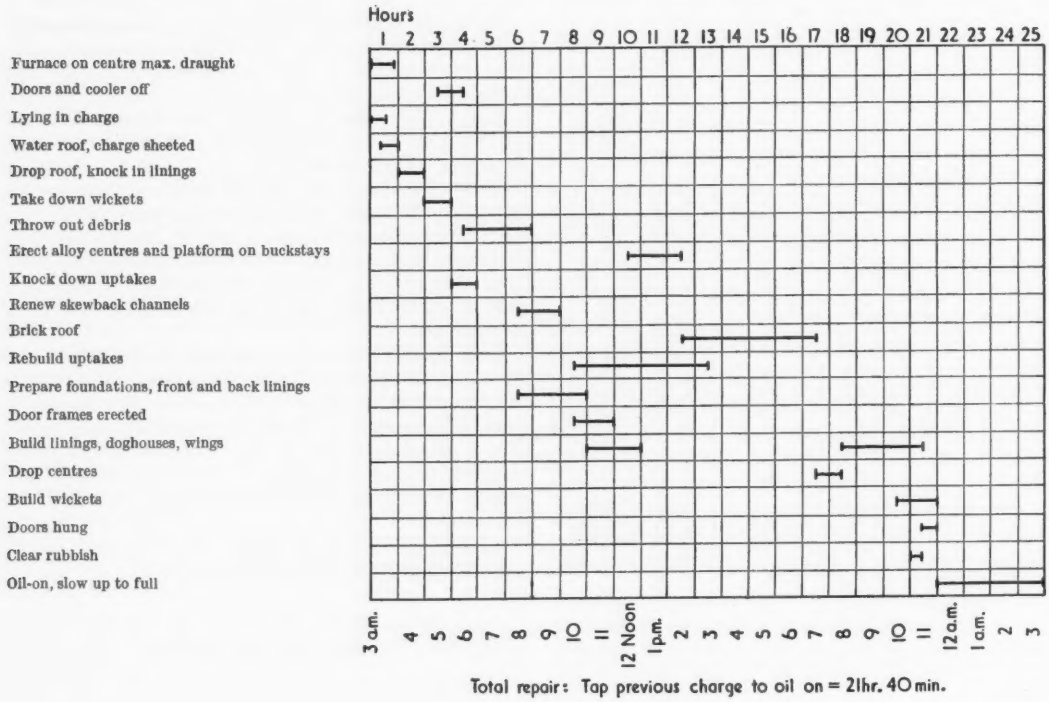

Hours
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Furnace on centre max. draught
Doors and cooler off
Lying in charge
Water roof, charge sheeted
Drop roof, knock in linings
Take down wickets
Throw out debris
Erect alloy centres and platform on buckstays
Knock down uptakes
Renew skewback channels
Brick roof
Rebuild uptakes
Prepare foundations, front and back linings
Door frames erected
Build linings, doghouses, wings
Drop centres
Build wickets
Doors hung
Clear rubbish
Oil-on, slow up to full
3 a.m. 4 5 6 7 8 9 10 11 12 Noon 1 p.m. 2 3 4 5 6 7 8 9 10 11 12 a.m. 1 a.m. 2 3
Total repair: Tap previous charge to oil on = 21hr. 40 min.
Note: This repair was delayed owing to more cutting down on the banks than usual.

Fig. 1—Schedule of top repair: roof, linings and uptakes. (Based on data from Sparrow's Point)

Figure 1 shows the schedule for a fast top repair, *i.e.*, renewing a complete roof, re-bricking uptakes and linings on a 200-ton furnace. The total time from 'oil off' to 'oil on' is about 22 hr.

The repair times vary according to the success of the team work and the layout of the shop. Long practice and mechanical aids are required before quick repairs can be achieved.

In Fig. 1 times are broken down into ½-hr. increments, and a number of jobs overlap. The stages must be planned so that one set of men does not hinder another and so that heat and dust do not delay the speed of working. The schedule is shown in simplified form, since instrument mechanics, welders, fitters, and electricians will also be working on the furnace.

Before the work starts, new fully tested doors and coolers and new skewback sections must be ready on the stage to go straight to the job when required. If guns or tunnel coolers are to be changed, replacements must be ready beforehand. Other details, such as pressure hoses for cooling the roof, new door ropes, spare flexes of the correct length, pneumatic picks with good hoses, must all be provided before the job starts and must be coupled up and in working order. Nothing unforeseen must arise during the work.

The foremen supervising the work are generally allocated wholly to open-hearth repairs, and are thoroughly familiar with each detail. The men may be divided into masons, masons' labourers, and furnace wreckers. They are completely mobile and, in a plant with more than one melting shop, can be concentrated wherever the greatest pressure of work demands.

A typical American hot-metal shop with 12 furnaces of 180 tons would be manned approximately as follows:

	Total Men per Day	Men per Furnace per Shift
Masons	70	1·7
Mason's labourers	75	1·8
Wreckers	68	1·9

These men would undertake open-hearth repairs, roof patches, ladle repairs, runners, spouts. Large numbers of apprentices are often used on bricklaying. (American apprentices are, in fact, young men in their early twenties, owing to the higher school-leaving age.)

Everyone, from the superintendent downwards, connected with a furnace repair wears a protective hat and steel-toed boots. Sometimes goggles are worn and occasionally a face mask, but generally silica dust is kept down by the liberal use of water. Speed of working is not sacrificed on the grounds of safety, yet safety regulations are stringent and accidents are few.

Wrecking the Furnace

When the last tap has finished, the furnace is put on centre with maximum draught and a lying-in charge is put in. This consists of all the limestone, ore, and part of the scrap, the hearth being filled to sill level.

The charge is sheeted or, alternatively, large boxes are placed on top, and the roof is heavily watered from below and above. The charger then knocks down the front linings and, with a peel, drops the roof by one or two powerful blows on the skewback channel at each door. Alternatively, holes may be cut in the roof either manually or by blows from the charger and crane hooks used to lift and drop the roof.

A large labour force may be used to throw out the bricks by hand—some down the uptakes and some on to the charging floor where they are pushed down the slag hole into the valve pit. If boxes are used, they will be lifted out by crane, taking a large proportion of the bricks. The ideal arrangement would be to throw all the bricks out over the back lining in the pitside so that work could proceed on the front of the furnace, but this is not easy. The bricks lying in the valve pit can be pushed by bulldozer into the casting bay and loaded by grab or shovel into wagons or lorries.

At the same time, doors and coolers are taken off, and the slag-pocket wickets and uptakes are knocked down. Slag is removed sometimes by manual labour, with pneumatic picks, but very often by casting-bay cranes. Two methods are common: (1) a sling is placed around the lump of slag, using false walls and sand on the floor; or (2) a bloom or slab, built into the pocket, prises up the slag so that it can be drawn out. The aim is to get the slag out in one lump or in a few large pieces. Explosives may also be used.

Special track-type shovels, which can enter a slag pocket and throw out bricks backwards over the driver's head, are used in some plants. This work is done at speed and heavy equipment is used to the full.

Building the Furnace

As soon as the charge is cleared of bricks, four pneumatic hammers, with two men on each, are used to cut down for the lining foundations. Skewback channels are renewed, and door frames and roof centres are erected. Light-weight metal centres used for building the roof can be handled by two men.

Building now begins, and in some plants use is made of a hanging platform on the buckstays. Roof bricks on pallets are placed by fork-lift trucks on this platform, which is clear of the charging-bogey tracks. Bricks are placed in through the doors in the front linings, and at the ends and back for the uptakes and back linings. The fork trucks must be small and easily manoeuvred.

The bricks may be brought to the furnace by wagons on the scrap-box roads or by lorry. Sometimes a complete gondola car of roof bricks is lifted by crane on to a stand at the furnace and the bricks are unloaded direct on to the roof.

All bricks must be delivered to the furnace in the correct order, size, and quality. Errors may mean time lost and disorganization of the sequence of work.

Warming Up

When the repair is completed, furnaces are brought up to temperature relatively quickly. After a general repair, charging commences about 15 hr. after first lighting up, and the first tap some 27 hr. later.

At Lachawanna close attention to heating-up rates has reduced the time to tap after repairs are com-

pleted to an average, for a year, of 22 hr., and on one occasion to 16½ hr. Initial warming up is started as soon as top repairs are completed and before bottom repairs are finished. Such fast times are possible since about 75% of the expansion in a silica brick takes place below 600° F. Up to 600° F. great care is taken, but above this the heating rate is rapidly increased.

BENEFITS OF HIGH AVAILABILITY

A simple calculation will show the increase in output obtainable by increasing availability. Consider a shop containing 12 furnaces of 200 tons, at (1) 80% and (2) 95% availability:

Availability	80%	95%
Average number of furnaces working per week	9·6	11·4
Average furnace weekly production per furnace, tons	2800	2800
Weekly shop production, tons	26,880	31,920
Increased weekly production, tons	...	5,040
Increased production for the year, tons	...	262,080

To reach and maintain 95% availability the cost of repairs per ton may be higher than on 80% availability, but the effect on the overall shop cost of the increased tonnage more than offsets this. The main consideration, however, is the extra output and the resulting overall economy of the works.

Discussion on the Papers—

REPAIR AND MAINTENANCE OF OPEN-HEARTH FURNACES IN GERMANY*
REPAIR AND MAINTENANCE OF OPEN-HEARTH FURNACES IN U.S.A.†

Dr. Ing. **A. Mund** introduced the paper on the repair and maintenance of open-hearth furnaces in Germany, and Mr. **I. Scott-Maxwell** introduced the paper dealing with American practice.

Mr. **G. R. Bashforth** (Round Oak Steel Works, Ltd.): These papers bring out the fact that, on the average, the results in Britain, so far as furnace availability is concerned, are very much lower than in America. Perhaps this is due to three causes. First, in Britain the layout of some plants does not permit the full use of mechanical devices for wrecking and rebuilding furnaces. Where mechanical devices and aids can be used, British figures are approaching, if not equalling, American availability. The practice of having a standby furnace and also complacency in carrying out repairs may be other factors.

Four factors affect furnace availability:

(1) Prolongation of furnace life. The Americans appear to go to the extreme of not caring how quickly they burn down their furnace, instead of trying to obtain maximum life by the correct selection of refractories or by attention to furnace design
(2) The correct scheduling of repairs and adherence to that schedule
(3) The speed at which repairs can be done
(4) The time taken to preheat before recommencing production.

Provided that the plant permits it, every possible mechanical aid must be used to reduce the repair period to a minimum. Also, the job must be organized so that there is no delay in the disposal of the debris or the assembly of materials and bricks.

To illustrate these points I will outline what we have tried to do on the new plant at Round Oak. The plant has five nominal 100-ton basic open-hearth furnaces of the Venturi type, which are actually tapping about 120 tons. The water-cooling consists of six horse-shoe pipes on each gas port and water-cooled door frames and skewbacks. The port blocks are chrome-magnesite, while the rest of the more vulnerable parts of the furnace is constructed with best silica bricks.

The life of a furnace is largely controlled by the roof life and to a lesser degree by the life of the ports and sometimes by the regenerators.

Our former melting shops consisted of two 30-ton tilting furnaces and five nominal 60-ton fixed furnaces. By careful planning we were able to achieve a furnace availability of 81·2%. When the new plant came into operation there were no records to guide us, but after about six months' operation a schedule (Fig. A) was worked out. We were trying to operate on a campaign of 32 weeks with an intermediate top repair at the end of 16 weeks for the roof, facing of the ports, and clearing out the slag pockets.

The *A* furnace followed the schedule closely, but *B* furnace had an unfortunate port failure, which made us wonder whether our port design was quite right. The schedule on the other furnaces was slightly affected by the shortage of raw materials. The furnace availability over the period, however, was 86·4%, although the actual production period was only 77·6%, owing to the shortage of raw materials.

At one point we got badly out of step and that is why I emphasized the importance of adhering to the schedule. Owing to the shortage of raw materials, repairs to *D* furnace were delayed for nearly three weeks, after which they were carried out in 12 days. Owing to a continued shortage of raw materials the furnace was not gassed and the schedule was dislocated, resulting in more than one furnace being under repair at the same time later in the period.

The *B* furnace repair in March, which consisted of a new roof, new ports, and front wall, occupied 5 days, 19 hr. 10 min. from 'gas off' to 'gas on.' Other interesting data were: *C* furnace in August had half a roof in 1 day, 20 hr. 50 min.; *D* furnace had half a roof in 2 days, 2 hr. 40 min.; and in October *B* furnace had a similar repair in 2 days, 1 hr. 20 min. The roof life was variable, but the average was then 10·9 weeks.

The collapse of the port on *B* furnace in March was followed by further trouble, there being a tendency for the port to fail just behind the water-cooling pipes. The design was therefore amended so that the uptake wall gave a little more support to the arch of the gas port, as shown in Fig. B, where a slight curvature of the uptake wall, which extends just above the base of

* *See* pp. 373–377. † *See* pp. 378–382.

the semi-arch of the gas port, will be seen. This feature has undoubtedly prolonged the life of the gas ports.

Towards the end of the 1951 schedule and the beginning of 1952 there was considerable roof trouble, due to the deterioration of the scrap and the desire to maintain rapid charging rates, which resulted in a large gouge opposite each door. The roof was therefore raised from 4 ft. 4 in. above sillplate level to 5 ft. above that level, which completely removed this weakness. This is another instance of the importance of furnace design.

Figure C shows the schedule for 1952, again based on a 32-week campaign, with an intermediate top repair after 16 weeks, which, incidentally, was not quite realized. There was trouble with the roofs in January and February, due to trying to force the rate of charging. After raising the roof a gouging occurred along the back-wall for 5–6 ft. on either side of the taphole. To try to overcome this the roof was thickened at that point from 12 to 15 in., but after the second trial on *A* furnace in February 1952, which only lasted 4½ weeks, the practice was discontinued. In March a complete roof repair on *A* furnace was carried out in only 1 day, 14 hr. 30 min. from 'gas off' to 'gas on,' and there were some fairly quick repairs later in the year.

After the August stoppage, roof collapses occurred on three furnaces within 20–30 min. of gassing. It is believed that those roofs had worn slightly over the back and collapsed because of lack of camber. As originally designed, the roof had a radius of 20 ft., which means a rise of about 2 ft. 1 in. or 1·4 in. per foot of span. The radius was altered to 18 ft., giving a rise of 2 ft. 5 in., or just over 1·6 in. per foot of span, and since then there has been no further trouble. The time from the first collapse at 10.20 a.m. on 8th August to the time of re-gassing the last furnace at 10.50 a.m. on 10th August was 48½ hr. About three-quarters of the roof was involved in each case.

A zebra roof was also tried, to overcome the difficulty of the vulnerable point over the taphole, and after 12½ weeks the results were encouraging, the chrome-magnesite bricks being in good condition, but the silica bricks showed signs of wear. This roof consisted of a patch 12 ft. 6 in. on either side of the taphole, extending 7 ft. into the centre of the furnace, and comprised alternate rows of super-duty silica bricks and chrome-magnesite bricks. It unfortunately collapsed, owing, it is believed, to insufficient camber, but a further trial may be made in the near future.

A few months ago a structural alteration was made by leaving three holes, 6 × 4½ in., in the top course of the back wall, one immediately over the taphole and one 6 ft. either side of that point. It had been calculated that these holes would allow sufficient infiltration of air at these points to neutralize the eddy current which was causing the gouging of the roof. The furnace concerned in the first experiment has now been in service for nearly 14 weeks and is showing no sign of erosion at that point.

The checkers have given some trouble, due not so much to failure as to choking up. After 32 weeks the condition of the bricks was good, but there was a large amount of deposit. Best silica is no longer used for the top courses because of slag attack; a high-alumina fire-brick gives much better results and good recovery.

On the basis of these lessons, the 1952–53 schedule has been worked out (Fig. D). For a top repair—that is, not including regenerators—the furnace can be cooled down in 16 hr., the top repairs completed and the slag pockets cleaned out in 6 days, the ramming in 8 hr., preheat prior to gassing in 1 day, and be 'on gas' 1 day before charging; that is, a total of 9 days from 'gas off' to re-commencing to charge. A general repair takes 2–2½ days longer. On the schedule there are eight general repairs of 11 days and six top repairs of nine days, giving a total of 142 days out of the 1750 days available for the five furnaces, *i.e.*, an average furnace availability of 91·8%. For the first sixteen weeks of that schedule repairs have required only slightly under 7½ weeks, which on a five-furnace basis gives a furnace efficiency of 90·9%. It would appear, therefore, that this schedule is not very far out and that it is not far below American standards.

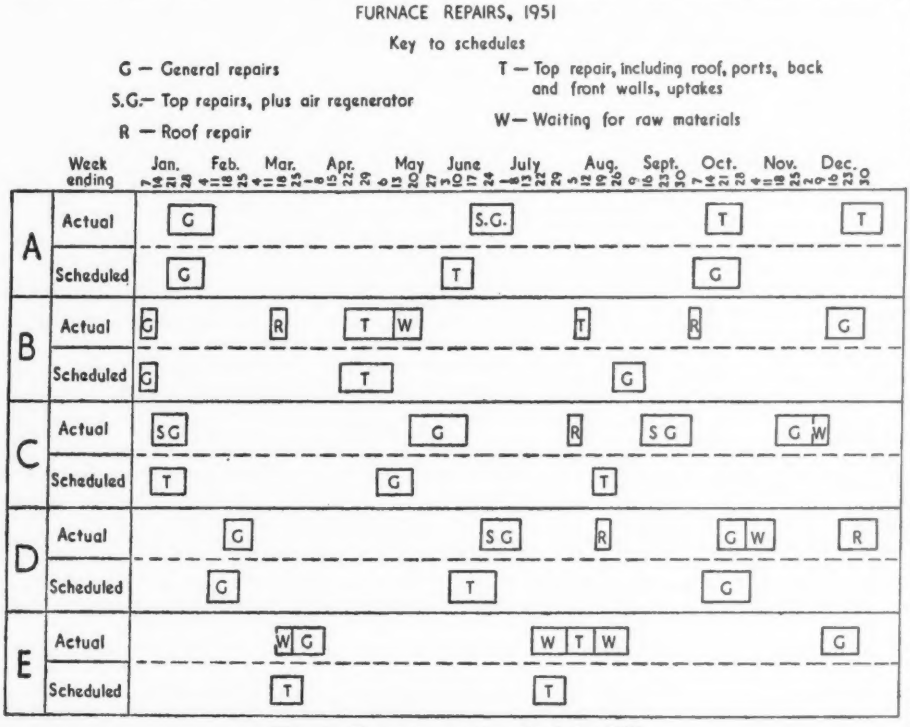


Fig. A—Furnace repair schedule, 1951

Mr. **H. G. Hilton** (Plant Maintenance Productivity Team): It has been suggested that the observations of the specialist team which toured the U.S.A. to investi-

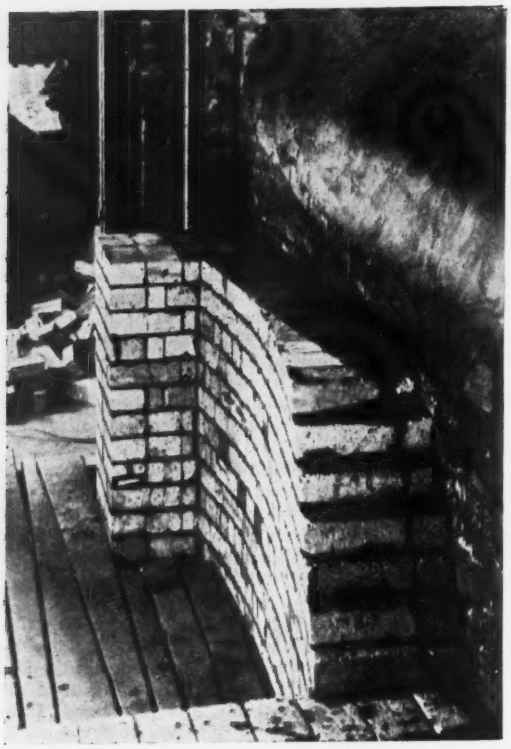


Fig. B—Amended design of uptake wall

gate plant maintenance may have some bearing on the paper on American practice. Unfortunately, we did not visit any American steel plants, as it was thought that the specialist techniques involved would not be of general interest, but I am personally of the opinion that the general principles are quite important. We endeavoured to include in our report the best points of practice in both countries and to recommend a method of looking at general maintenance which seems to have much in common with what we have heard about the planning and scheduling of open-hearth furnace maintenance.

The team believed that the vital element in any operation such as repairing a furnace is not only scheduling to decide when to do the job, but also very careful and detailed planning on how it is to be done. That is the most important recommendation we have to offer.

The plants that we saw, some 16 in number, were very varied and in all sorts of industries, starting off with a brewery and ending with a furniture factory, and employing from 300 to 15,000 people. The only plant visited that had problems similar to those of the iron and steel industry was an oil refinery. At this plant much attention was paid to scheduling and planning, and engineers were engaged entirely in reviewing technical methods. If they had been doing a job in the same way for two years, they felt that it was time to think of a better way to do it. That was certainly borne out in the plant. The detail of their planning was excellent.

In regard to mechanical aids, they said that the individual horse-power of a man was about $\frac{1}{8}$ h.p., so that if he were given a mechanical aid with a power of 1 h.p. he could be expected to do the work of eight men. Their capital investment for mechanical aids for maintenance was equivalent to 20,000 dollars per man employed in maintenance.

Mr. R. Wogin (Appleby-Frodingham Steel Co.): Although we can and must improve our productivity, there is a fundamental reason why, on the average, the British repair methods and results must lag behind the Americans, and this is not, as Scott-Maxwell and Evans seem to imply in their paper, that we are inferior in our ability to co-ordinate and organize. The fundamental difference between our repair times and availability is due to the universal use in America of fuels which do not need preheating.

The authors state in their paper that " Over 90% of American open-hearth steel is made with rich industrial fuels," but they ignore the significance of this and merely recommend that we use such fuels to burn the furnace down.

Nowhere has the Productivity Report shown how much extra productivity is due to features of the oil-fired furnace other than that they are oil-fired, for which a conservative 10% extra production has been allowed. That is a gross underestimate. It is true that 25% of the furnaces in Britain have gone over to oil, but 25% of them have not been fully designed for oil-firing; many have been changed over to oil, but are ready to revert to gas at short notice. The Americans reached the position of having 90% of their furnaces of oil-fired design some years ago, and they have the advantage of that design in many ways, one of which is in their repair times. They use high-grade fuel because their cost of fuel is one-third of ours and because their high-purity ores mean that they do not have a high coke consumption in their blast-furnaces and therefore no excess of blast-furnace gas to use in their steel furnaces.

A British gas-fired furnace may have a 10-day repair, compared with 4 days, which is the best time at Sparrow's Point. Of that difference of 6 days, 4 days lie in the design, the difference between an oil-fired and a gas-fired furnace. I see no reason why we should not do a repair in 4 days with an oil-fired design, but for the gas-fired furnace there is that difference.

In gas-fired tilting furnaces, similar to those at Appleby-Frodingham, the wall between the gas and air slag pockets is 4–5 ft. thick; it must be rigid to prevent gas and air from mixing, and the whole thing from burning down. That is carried right through the checkers, the slag pocket, the uptakes, and the gas ports. All that extra brickwork holds heat and involves the extra cost of brickwork, with extra wrecking and rebuild time.

Fast furnace repairs depend on ' approachability ' and ' accessibility.' If this 25–50% extra brickwork is missing, the system cools much more rapidly, giving ' approachability.' There is greater ' accessibility,' because there is more space in each section; machines can get in and handling is minimized.

Rapid slag-removal from the pockets is the essential to a fast repair. In a gas-fired furnace the uptakes enter at the side of the slag-pocket arch. With an oil-fired furnace the uptake comes centrally into the middle of the one pocket, and the slag falls straight into the pocket itself and does not run down the false walls. Also, there is no ' hot wall ' separating the gas and air pockets. These two features explain the greater ease of slag removal with the oil-fired design. The slag does not cement itself into the walls.

Finally, brick recovery is essential in a gas-fired furnace with so much brickwork. That saving will offset two or three days of furnace repair time.

Despite all these difficulties, at Appleby-Frodingham the latest general repair on a 300-ton tilting furnace was completed in 5 days, 1 hr., from ' gas off ' to ' commencing to warm up,' and the time from ' gas off ' to tap was 7 days, 21 hr. That includes ramming in a bottom,

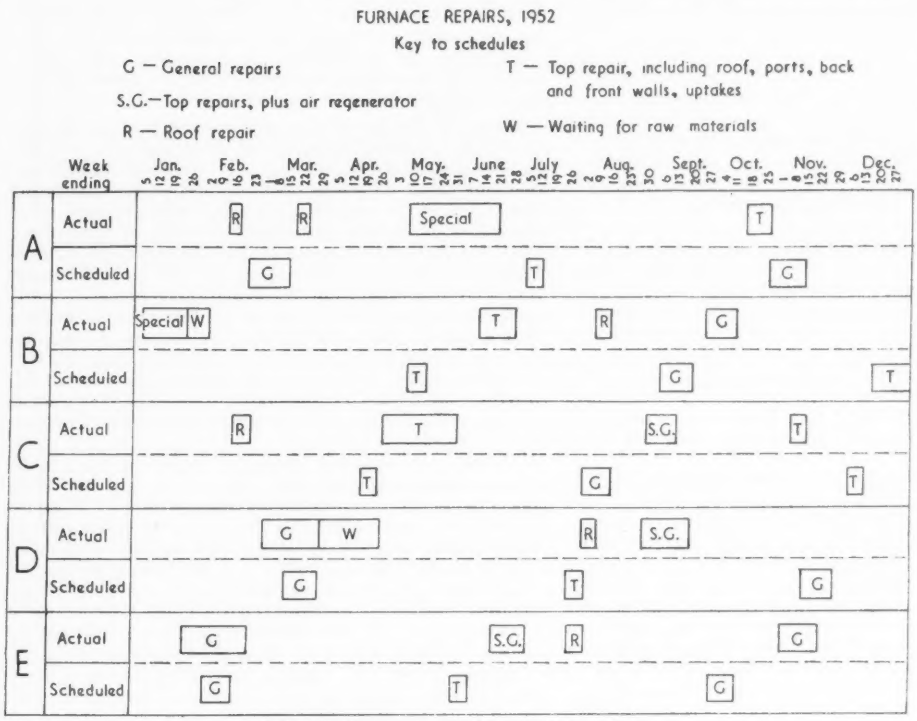

FURNACE REPAIRS, 1952
Key to schedules
G — General repairs
S.G.—Top repairs, plus air regenerator
R — Roof repair
T — Top repair, including roof, ports, back and front walls, uptakes
W — Waiting for raw materials
Week ending
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
A Actual R R Special T
Scheduled G T G
B Actual Special W T R G
Scheduled T G T
C Actual R T S.G. T
Scheduled T G T
D Actual G W R S.G.
Scheduled G T G
E Actual G S.G. R G
Scheduled G T G

Fig. C—Furnace repair schedule, 1952

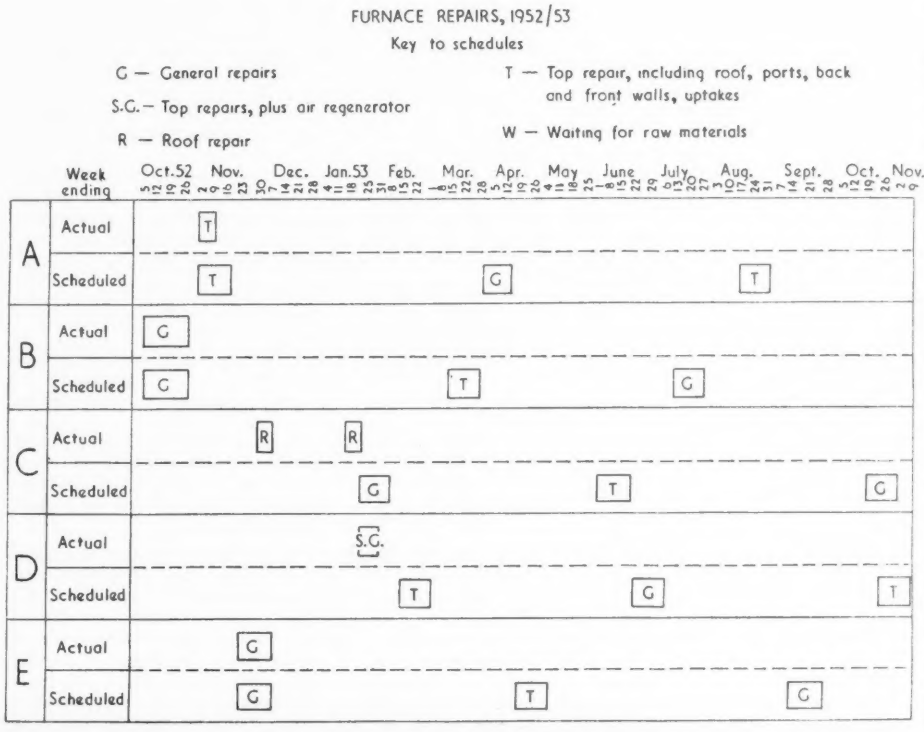

FURNACE REPAIRS, 1952/53
Key to schedules
G — General repairs
S.G.— Top repairs, plus air regenerator
R — Roof repair
T — Top repair, including roof, ports, back and front walls, uptakes
W — Waiting for raw materials
Week ending
Oct.52 Nov. Dec. Jan.53 Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov.
A Actual T
Scheduled T G T
B Actual G
Scheduled G T G
C Actual R R
Scheduled G T G
D Actual S.G.
Scheduled T G T
E Actual G
Scheduled G T G

Fig. D—Furnace repair schedule, 1952–53

removing 140 tons of slag from the four slag pockets, replacing air checkers to valve level, and redesigning the block and uptakes.

If we allowed our gas-fired furnaces to be driven at high speed, what would Mr. Evans and Mr. Scott-Maxwell say to the first hand when he told the manager: "I have burned the furnace down; you build it up"?

Can Mr. Evans give any idea of the availability for the Abbey plant after one year of operation?

In regard to the high-alumina bricks which Dr. Mund uses in the checkers, what is the extra cost and extra life? Is there any saving as compared with silica?

Dr. Ing. **A. Mund**: In the first 8–10 courses the special high-alumina bricks with 55% of Al_2O_3 are used. The price of these bricks is more than double that of silica bricks or of normal fireclay bricks with up to 40% of Al_2O_3. The dangerous zone in the checkers is, in most cases, about $1\frac{1}{2}$ m. from the top course, and it is therefore very important to have high refractory bricks in the first 8–10 courses.

Mr. **A. Provis** (Guest Keen Baldwins Iron and Steel Co., Ltd.): The co-ordination which Evans and Scott-Maxwell mention between the repair and production de-

partments is very real, helped as it is by the equivalent status of the shop superintendent and the superintendent of masons. This ensures less of a bias in favour of the production department with equal representation at top level helping to curb furnace abuse. On the floor there is a trend away from the necessity of co-operation between production and masons' departments. Fork-lift trucks and pallets remove the need for crane lifts, which dislocate the supply of hot metal, while the platforms used ensure that there is no dislocation of scrap-bogie movement.

Once a furnace comes off the line the shop superintendent can forget it, and it is up to the superintendent of masons to bring it back as quickly as he can. No mere lip service is paid to schedules; they are attained or, if they are not, somebody is blamed for it. This control works down the line to the individual charge hand actually on the job, who is given a particular amount of work to do in a particular 8-hr. shift. The American foreman and charge hand is educated to a sense of responsibility and is willing to accept it—and is paid to do so.

The authors have mentioned some methods by which furnace life is increased per campaign. There are others: First, extensive use of basic brick, including experimentation with zebra roofs. Secondly, reintroduction of super-duty silica bricks, particularly in the eastern mills, with the manufacture of better products. Thirdly, provision of spray guns for inside furnace maintenance and for repair work in slag pockets and checker chambers. Fourthly, emphasis on efficient checker-clearing systems, allied to installation of soot blowers and flue cleaning by specially equipped personnel during the campaign.

The production figures can be obtained only by the ability of the masons to repair and rebuild furnaces as fast as the furnacemen burn them down. Techniques have been evolved which are simple and conducive to the quick repair times and high furnace availability figures reported at most mills—both old and new. On a particular repair job, a 932-sq.ft. roof was dropped and relaid with 12-in. bricks from 7.37 a.m. to 2.50 p.m., 'oil off' to 'oil on,' on a June day, despite an outside temperature of 95° F. and a high humidity. The speed of installation was ensured by a large labour force of 15 masons and 29 helpers; by fast bricklaying (iced water in paper cups being taken on top of the furnace); by a minimum amount of piping, beams, bars, and steelwork to cause interference on top of the furnace; and by a continuous flow of materials, palletized bricks being handled by 4000-lb. capacity fork-lift trucks from box cars to the scaffolds on the front and rear of the furnace.

This works employed 250 masons and 55 apprentices for 8 blast-furnaces and 36 open-hearth furnaces, the furnace availability figure of the latter being 95·4%. There was no incentive bonus paid at that time and the speed with which rebuild and repair work was carried out was all the more remarkable because the masons engaged on hot patching were paid at the same rate as those on cooler jobs. Discipline and a pride in the work performed achieved results without recourse to financial 'bribery.'

American practice is not perfect: the system of soaker charges on rebuilds cuts down on hearth and backwall maintenance with the inevitable result of frequent breakouts. Such malpractices represent the price that is paid for the increased production that is desired and obtained. In most of their plants the scale of operations renders possible the employment of larger forces of masons and maintenance personnel than in Britain.

The Americans have faced the problem that is faced in Britain today, and they have solved it. The engineers present have been told what to do: it is the management's duty to collaborate, not only by educating and disciplining the labour force to a sense of urgency, but also by considering the economics of increasing manpower availability in relation to speedier repair times and a consequently greater productivity.

Mr. **R. W. Evans**: We are glad to note that Mr. Bashforth's repair schedule takes him up to just under 91%. In regard to Mr. Wogin's remarks, we would point out that our paper describes practices and performances in the U.S.A. We certainly did not intend to cast any aspersions on British plants and methods of operation. We fully realize that there is a difference between gas firing and oil firing, but we have tried to emphasize that the Americans are repairing their furnaces considerably faster than we are. It may be said, of course, that so far as the repair of roofs is concerned there is not a great difference between gas and oil firing, and we should be able to do roof repairs as fast as the Americans, provided that we have all the facilities. The fact that a furnace is gas-fired should not affect the speed with which we should put on a roof.

In regard to drawing of slag out of the pockets, and the complications that arise when there are two slag pockets per end, complications are still present if there is only one, as very large lumps result. We have pulled lumps of slag of up to 180 tons out of the Abbey furnace slag pockets. We are lucky to have strong cranes so positioned that we can get a grip on these lumps, but there are problems in dealing with them.

On the question of the availability of the Abbey plant, we are regularly working 7 out of the 8 furnaces installed. Although there have been periods when we could have put the 8th furnace on and brought our availability up to 90% or so, at present we cannot do this because of shortage of ingot cars, slag pots, etc.

We have had experience of gas firing in the two old shops, one shop having 6 furnaces producer-gas-fired and the other 6 furnaces on mixed gas. Towards the end of the producer-gas-firing days, when the shop started to be reconstructed, we worked the availability on 6 furnaces up to nearly 90%. We then started, however, to rebuild the shop, furnace by furnace, and that interrupted the run of the shop, so that we had to drop from 6 furnaces to 5.

It is not altogether true to say, however, that because a furnace is gas fired it must necessarily give a low availability, though we agree that with gas-fired furnaces it would be difficult to reach an availability of 96–97%. We were most interested to hear Mr. Provis's remarks.

Mr. **G. H. Timmins** (Stewarts and Lloyds, Ltd.): At what stage is it advisable to burn the furnace down; is it while charging or refining?

The temperature has to be kept within casting limits, so it cannot occur then, and if a temperature above 1650° C. will damage the roof it would be ridiculous to exceed this.

We may be too cautious in striving for a roof life of over 500 heats, but I would like to have explained to me the necessity for burning the furnace down and the best time to do it, bearing in mind that proper care very often means greater furnace availability.

Mr. **R. W. Evans**: We say in the paper that the Americans realize the great importance of maintaining the roof at its maximum temperature throughout the charge, from commencing to charge to tapping. There is no doubt that, if during the charging period the roof is kept to its maximum temperature by high fuel inputs, there is a great risk of burning the roof; flame reflection from the scrap occurs, which causes intense temperatures at one point on the roof. That, in fact, is what the Americans do; they pour fuel into the furnace when

Table A

PROPERTIES OF FUELS USED IN GERMAN STEELWORKS

Fuel	Calorific Value	Theoretical Combustion Air	Waste Gas	Air Required, cu. ft./therm	Waste Gas Required, cu. ft./therm	Theoretical Flame Temp., ° C.
Gaseous Fuels	B.Th.U./cu. ft.	cu. ft./cu. ft.	cu. ft./cu. ft.			
Blast-furnace gas	106	0·77	1·67	634	1671	1530
Lignite producer gas	153	1·20	2·02	863	1453	1840
Pit-coal producer gas	138	1·09	1·94	872	1552	1780
Coke-oven gas	440	4·09	4·81	1023	1203	2000
Mixed coke-oven/blast-furnace gas	231	2·00	2·80	953	1313	...
Liquid Fuels	B.Th.U./lb.	cu. ft./lb.	cu. ft./lb.			
Lignite tar oil	16,200	154	160	941	978	2140
Pit-coal tar oil	17,100	161	169	934	980	2150
Tar	15,300	147	151	953	978	2170
Mineral-oil residues	17,650	166	174	933	978	2150

charging so as to melt down the metal quickly, and their roofs do get burned. In new 275-ton furnaces, when charging, they put in up to 1000 gal./hr. with a single oil burner. They do so with one object: to heat up the roof quickly to its maximum temperature, and so obtain the maximum melting rate in the furnace. If a furnace has uptakes or flues that are too small to take away large volumes of combustion products this cannot be done. If it were possible to enlarge them, that would be one way of using more fuel to obtain a higher output.

CORRESPONDENCE

Mr. **H. G. Jones** (Steel Company of Wales, Ltd.) wrote: Has Mr. Pluck taken, or does he propose to take, any steps to preserve the shape of the roof when using super-duty silica bricks? There are a number of possible procedures which, while not economic with an ordinary silica crown, might be profitable and indeed necessary if any advantage is to be gained from super-duty silica bricks.

Mr. **A. Bartholomew** (Park Gate Iron and Steel Co., Ltd.) wrote: I should like to ask Dr. Mund two questions: (1) Are special bricks used to build the checkers so as to obtain passages that widen from top to bottom, or are ordinary-sized bricks used? (2) What is the size of passage at top and bottom?

Dr. **D. F. Marshall** (Park Gate Iron and Steel Co., Ltd.) wrote: The first three papers considered the repair and maintenance of open-hearth furnaces under three main headings: (1) Plant layout, (2) methods of extending the life of an operating furnace, and (3) quick repair techniques applied to shortening the repair time of furnaces out of commission.

It is very opportune that the paper by Mund and Kreutzer, although mentioning these points, also emphasizes the importance of furnace operation and fuel usage as a fourth factor affecting furnace availability. In Britain and in Germany the limitations of existing plant layouts direct attention principally to the second, third, and fourth factors in increasing furnace availability.

Mund and Kreutzer clearly demonstrate the obvious, but often unappreciated, fact that the simplest way to increase outputs is to build larger furnaces, and a second important method is to use better quality fuels. Both these fundamental facts are admirably illustrated in their Figs. 1*a–d*. Would the authors agree that both these steps also give increased furnace availability?

Figure 1*c* shows, for example, that the output rates of furnaces in the 60–100-ton range are, on the average, higher than for British furnaces in the same size group. Is this due to better furnace design or does the lighter German metallurgical load account for the difference? Similarly, do all the furnaces used in the preparation of Figs. 1*a–d* work under similar metallurgical conditions? If not, then the validity of the conclusion drawn would be open to doubt. Could the authors give typical analyses of the pig irons used and the total slag bulk at melting and at tapping? Provided that tapping-slag bulks do not exceed 12–14% of the tapping weight, comparisons of the type in the paper are quite feasible, as has been shown in American practice.

The analysis of furnace-operating data for the various types of fuel practice is a useful piece of work. Could the authors complete it by giving the principal properties of the fuels used in Germany? The authors leave little room for doubt that producer gas is one of the lowest ranking open-hearth-furnace fuels. Have they any information on the effect of varying the proportion of coke-oven gas in oil/gas mixtures, or of applying coke-oven gas at high pressures in this mixed-fuel practice?

The authors commented on the wear on central-uptake furnaces. What steps were taken to overcome this wear? Basic-lined uptakes do not always give a granular deposit in the slag pockets. In our own practice, where the air preheats were relatively high, this construction actually gave one of the densest slags ever encountered at Park Gate. It seems, therefore, that the nature of the slag depends not only on physical and chemical characteristics arising from the constructional materials employed, but also on the temperature conditions.

Burning additional gas with an intentional feed of infiltrating air is a very unusual method of cleaning checkers. Can more information be given on the technique of this unique process? What is the nature of the dust deposited which permits it to be melted away without apparent harm to the brickwork?

The use of air-cooling to extend roof life is very interesting, and this intentionally applied cooling is obviously better than the method frequently applied, *viz.*, working the furnace under suction, which protects the roof but gives poor results in furnace operation. Since compressed air is expensive, could the authors give the amount of air used for this purpose?

The comments on the advantages of splitting up the fuel stream are of particular interest since they confirm similar views expressed on practice in America.

On the subject of automatic control, we agree with the authors that the impulse-giver requires careful control. If attention is given to this, then, as has been shown in British furnaces, there is no difficulty whatsoever in

Table B

ANALYSES OF DUST AND SLAGS IN CHECKERWORK

	Checker Layer	SiO_2, %	Al_2O_3, %	CaO, %	MgO, %	Fe_2O_3, %	Mn_3O_4, %	ZnO, %	SO_3, %	P_2O_5, %	Melting Point, °C.
Reaction products	1	7·57	9·50	10·69	6·61	58·00	1·83	7·00		0·135	
" "	5–6	16·11	16·90	16·99	5·61	33·25	1·07	7·70		0·203	
" "	8	18·61	15·90	13·91	4·33	33·13	1·14	7·35		0·303	
" "	12–15	24·24	15·15	22·83	4·89	24·65	0·61	5·40		0·372	
Slag deposits	10	25·47	14·47	26·48	6·34	22·80	1·37				
" "		25·90	18·32	19·68	5·84	23·55	1·41				
" "	12	28·51	16·54	25·19	4·71	20·40	1·18		0·068		1120
" "		32·84	20·35	21·04	3·62	15·20	0·32				
Coke-like deposit	8	14·48	10·22	27·92	6·65	36·22	1·30		0·38	0·337	1220
Soft, slightly sintered dust	12–15	6·48	8·50	27·43	6·46	30·85	1·37	3·50	13·63	0·507	
Loose dust	18–24	6·68	7·82	23·50	6·97	28·65	1·60	4·20	21·65		1340
Flue dust		6·96	4·76	24·81	6·90	28·30	1·53	4·10	20·76		

applying automatic control based, for example, on roof-temperature measurement.

AUTHORS' REPLIES TO CORRESPONDENCE

Dr. Ing. **A. Mund** wrote in reply: In his written contribution Dr. Marshall asked whether a better furnace efficiency could be obtained by building larger open-hearth furnaces and by improving the furnace control. The control of furnace operation has, above all, an important effect on furnace life. A uniform and complete distribution of waste gases in the checkers and an efficient draught regulation ensure a long life of the air chambers, which is essential for a high furnace availability.

The use of better quality fuels also improves the furnace efficiency. Coke-oven-gas, mixed-gas, or oil-fired furnaces are more efficient than producer-gas furnaces since time off for cleaning the gas pipes is avoided, the furnace design is more simple, the ports have a higher durability, and repair times are very short.

As regards furnace size, the standard curves shown in the paper, particularly Fig. 1*d*, show that furnaces below a certain capacity are not economical, irrespective of the fuel used. Large furnaces have a long life and therefore a high efficiency, provided that the flame baffling is good.

It is agreed that the work involved with slags, *i.e.*, the metallurgical load, is much greater on furnaces in Britain than on those in Germany. We are trying to improve existing plants by better furnace designs and by a closer control over conditions.

The average analysis of the pig iron used in cold- or hot-metal practice is as follows:

Mn, %	P, %	S, %	Si, %
Approx. 2·0	<0·3	<0·05	Approx. 1·0

In Germany, the average total consumption of burned lime charged and fed is 45 kg./ton and of dolomite 30 kg./ton. The average quantity of slag is 10–12%, or more if the scrap used is very light, if the charge is high in sulphur and phosphorus, or if high-quality steel is produced for which a single or double removal of slag is necessary.

In Britain a very good producer-gas coal with a high content of volatile constituents is generally available. The average calorific value of mixed coke-oven and blast-furnace gas used in Germany is 235 B.Th.U./cu. ft. The chief properties of the fuels used are given in Table A. The pit-coal producer gas has a calorific value 14% lower than British pit-coal producer gas, whereas the calorific value of lignite is nearly the same as in Britain. The German blast-furnace gas has a slightly higher calorific value.

The oil added to coke-oven gas is generally a maximum of 30% of the total heat consumption, and in some cases up to 50%. The coke-oven gas is not added to the oil at high pressure, as in America, but is nearly always below 40 in. W.G.

To reduce, as far as possible, the wear caused by the hot gases on the brickwork of the air uptakes at the end walls, water-cooling boxes are arranged at stage level and the end walls above these cooling boxes have relieving arches. The air uptakes are often enlarged downwards in trumpet form below the cooling boxes so that the slag drops off vertically without attacking the brickwork.

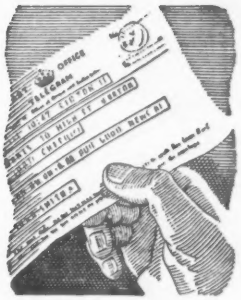
The end and side walls of the ports of producer-gas-fired furnaces are relined with chrome-magnesite bricks. Cooling pipes are often fitted in the walls of the air uptakes.

If the slag in the slag pockets of furnaces with basic-lined uptakes was dense and hard, presumably the port arch and possibly other parts of the port were of silica, so that a low-melting-point basic–acid slag would be formed. Experience in Germany is similar to that in America, *i.e.*, on furnaces with basic-lined ports and port arches the slag is granular and can be shovelled.

It is possible to clean the checkers by burning additional gas if the melting point of the dust deposited in the chambers is raised by its reaction on the brick surface, whereby products of reaction emerge. If the temperature of the chamber is raised for a short time to the necessary point, the brick surface softens and the dust deposits fall off into the dust flues. A deep shaft is required for observation of the process under the checkers, to avoid overheating. Furthermore, the upper layers of the checkers must be lined with high-alumina bricks. Table B shows analyses and melting points of dust deposits at various levels in a checker chamber.

Silica and chrome-magnesite roofs of rib- or box-type designs are not cooled with compressed air, but with normal ventilating air. Approximately 350,000 cu. ft./hr. and a static pressure of at least 11·5 in. W.G. are required for a 60-ton furnace.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Special Meeting in Holland

A Special Meeting of the Institute will be held in Holland from **Wednesday, 30th September, to Tuesday, 6th October, 1953.** The provisional programme includes visits to steelworks at Ijmuiden, Utrecht, and Rotterdam, and excursions to Delft and The Hague.

Further details of the programme will be given in the September issue of the *Journal.*

Bibliography on Tool Steels (1922-1953)

The Joint Library has recently received a number of copies of a B.I.S.R.A. document, "*Bibliography on Tool Steels* (1922–1953)." The references for the period 1922–1929 are selective, but later ones, taken from the Abstracts Section of the *Journal,* cover the subject fully. The material is divided into six sections: General; Melting and Casting; Working and Shaping; Heat Treatment and Surface Treatment; Properties and Tests; and Analysis.

Copies will be supplied by the Institute free of charge upon receipt of 1*s.* (postal order or stamps) to cover packing and postage.

Metal-Work in the Nineteenth Century

The Joint Library has received, as the result of a generous offer by the British Iron and Steel Federation, a copy of "*Metal-Work,*" a book which illustrates the chief processes of art-work applied by the goldsmith, silversmith, jeweller, brass, copper, iron and steel worker, bronzist, etc., during the middle of the 19th century.

NEWS OF MEMBERS

▶ Mr. E. B. Babler has been awarded the M.B.E. in the Coronation Honours List.

▶ Mr. J. Britton has been awarded the degree of B.Sc. in Metallurgy at the University of Wales, and is at present serving with H.M. Forces.

▶ Professor Bruce Chalmers has left the University of Toronto to take up the appointment of Professor of Metallurgy at the Division of Applied Science, Harvard University.

▶ Mr. S. C. Clifford has been appointed to the Board of Ferodo Ltd., as Works Director.

▶ Mr. A. F. C. Gardner has been appointed Northern General Manager of Gibbons Brothers, Ltd., at Stockton-on-Tees.

▶ Mr. N. L. Goodchild has left the British Iron and Steel Federation to become Managing Director of Cowlishaw, Walker and Co. (London), Ltd.

▶ Mr. K. Kornfeld has taken up the post of Head of the Metallurgical Section of the Quality Control Laboratory, Air Material Command, Royal Canadian Air Force.

▶ Mr. J. Strauss, Vice-President of the Vanadium Corporation of America, has received an Award of Merit of the American Society for Testing Materials.

▶ Mr. D. J. D. Unwin has left the United Steel Companies, Ltd., and has joined the Park Gate Iron and Steel Co., Ltd., Sheffield, as Assistant Chief Metallurgist.

Obituary

Professor D. Hanson, of the Department of Metallurgy, Birmingham University, on 12th June, 1953.

Mr. W. S. Reed, of Ebchester, Co. Durham, on 14th May, 1953.

CONTRIBUTORS TO THE JOURNAL

J. S. Curphey, F.I.M.—Steel Plant Manager at the Lackenby Works of Dorman Long and Co., Ltd.

Mr. Curphey was educated at Middlesbrough Technical School, and at the Constantine Technical College where he later became part-time Lecturer in the Metallurgy of Iron and Steel. In 1923 he joined the laboratory staff at the Acklam Works of Dorman Long and Co., Ltd., where he was appointed, in turn, chemist, metallurgist, and fuel technologist. He then took up the post of Assistant Steel Plant Manager at the Acklam, Cleveland, and Redcar Works of the Company, and in 1949 was appointed Steel Plant Manager at Redcar. He took up his present position in November, 1952.

J. S. Curphey

Mr. Curphey is a member of the Steel Practice Committee of the British Iron and Steel Research Association.

Eric William Nixon, B.Met., A.I.M.—In charge of the Ironworks Section of the Metallurgical Department of the Appleby-Frodingham Steel Company.

Mr. Nixon was born in 1921, and was educated at Brigg Grammar School. In 1938 he joined the Appleby-Frodingham Steel Company as a Technical Apprentice, meanwhile studying at Scunthorpe Technical College. He gained his final certificates in the City and Guilds Examination in 1940 and was awarded the Bronze Medal. He was then awarded a Lindsey Ironmasters' Scholarship to Sheffield University, where he graduated in Metallurgy in 1943. He then returned to the Appleby-Frodingham Steel Company and worked at first in the Steelworks Section and then in the Research Laboratory of the Metallurgical Department. He took up his present appointment in 1945, and has since been working on quality control, and plant research and development.

Mr. Nixon was made a Licentiate of the Institution of Metallurgists in 1946, and became an Associate in 1947.

E. W. Nixon

F. R. Maw

Frederick Raymond Maw, B.Met., L.I.M.—Metallurgist in the Ironworks Section of the Metallurgical Department of the Appleby-Frodingham Steel Company.

Mr. Maw was born in 1927, and was educated at Scunthorpe Grammar School. He joined the Appleby-Frodingham Steel Company in 1944 as a Works Technical Apprentice, meanwhile continuing his education at Scunthorpe Technical College. In 1947 he was awarded a Technical State Scholarship to Sheffield University, where he was awarded the degree of B.Met. in 1950. After graduation he rejoined the Appleby-Frodingham Steel Company, and took up his present position.

He became a Licentiate of the Institution of Metallurgists in 1953.

IRON AND STEEL ENGINEERS GROUP

The **Twenty-Third Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday, 28th October, 1953.** Two papers will be presented for discussion: "*Roll Design Research as Applied to Rolling Mill Development*," by B. Robinson and W. A. Lugar, and a paper on Rolling Mill Guides and Manipulating Equipment by W. Bailey.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Heat Treatment Practice

A Conference on Heat Treatment Practice was held by the Metallurgy Division of B.I.S.R.A., under the sponsorship of the Thermal Treatment Sub-Committee, at Ashorne Hill, on 15th–17th June, 1953. Mr. H. H. Burton, C.B.E., was in the Chair. The Conference, which was attended by over 230 members representing steelmakers, users of engineering tools, motor car manufacturers, furnace builders, instrument makers, and others, opened with a review of the work of the Thermal Treatment Sub-Committee over the past 17 years, made by the Vice-Chairman, Mr. W. C. Heselwood (Chairman of the Thermal Treatment Sub-Committee). Technical sessions were held on the heat-treatment of engineering steels, large forgings, and surfaces; surface treatments (involving change in composition) and the heat-treatment of surface-treated components; isothermal heat-treatment; and temperature measurement and control.

Films on flame hardening, bainite formation, and a modern pyrometer were shown, and an exhibition of modern temperature-measuring and controlling instruments was held in conjunction with the Conference.

NEWS OF SCIENCE AND INDUSTRY

Engineering, Marine, and Welding Exhibition

The next of this series of exhibitions will be held at Olympia, London, W.14, from 3rd to 17th September, 1953.

As in previous years, the Organizers have extended to all Members of the Institute an invitation to visit the Exhibition. Requests for complimentary tickets should be made, as soon as possible, to the Secretary, 4 Grosvenor Gardens, London, S.W.1.

Physical Metallurgy at Sheffield University

Applications for admission to the Postgraduate School in Physical Metallurgy of Sheffield University are invited from:

(*a*) Scientists already in industry, holding a degree or equivalent qualification, who have had at least three years' experience and wish to pursue more advanced studies in Physical Metallurgy

(*b*) Recent graduates in Pure Science or Engineering who wish to pursue a metallurgical career.

The session, which lasts from 5th October, 1953, to 3rd July, 1954, will be divided into five courses, each of five weeks duration, under the following headings: Metallurgical techniques; deformation of metals; solidification of metals; physical metallurgy of heat-treatments; and theory of alloy steels. Lectures will be supported by discussion groups and colloquia, and by experimental work.

The fee for a full-time postgraduate course is £50 per annum. Grants for tuition and maintenance are available for suitably qualified candidates. Full particulars may be obtained from the Professor of Physical Metallurgy, The University, St. George's Square, Sheffield, 1.

Société Française de Métallurgie

The Annual Autumn Meeting of the Société Française de Métallurgie will be held in Paris from 19th to 23rd October, 1953. Further particulars may be obtained from the Secrétaire-General of the Société, 25 rue de Clichy, Paris, 9e.

CORRIGENDUM

Corrosion of Buried Metals

In Table II (p. 11) of Special Report No. 45, "*A Symposium on the Corrosion of Buried Metals*," the analyses have been quoted as p.p.m. (parts per million). It has been pointed out that the figures should denote parts per 100,000.

TRANSLATION SERVICE

(The previous announcement was made in the July, 1953, issue of the *Journal*, p. 267).

TRANSLATIONS AVAILABLE

No. 469 (German). H. SCHUMACHER: "The Operation of the Low-Shaft Blast-Furnace." (Abridged) (*Stahl und Eisen*, 1953, vol. 73, Feb. 26, pp. 257–263).

No. 471 (German). K. GUTHMANN: "The Development of Blast-Furnace Gas Cleaning during the Last Ten Years." (*Stahl und Eisen*, 1953, vol. 73, Feb. 26, pp. 283–292).

TRANSLATION IN COURSE OF PREPARATION

(German). G. SENGFELDER: "New Results on the Pelletizing of Iron-Ore Concentrates." (*Stahl und Eisen*, 1952, vol. 72, Dec. 4, pp. 1577–1579).

CHARGES FOR COPIES OF TRANSLATIONS.—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS AND BOOK NOTICES

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MINERAL RESOURCES

Bristol Magnetite Deposit. W. K. Buck. (*Canad. Min. J.*, 1953, **74**, Jan., 55–57). This deposit, 35 miles N.W. of Ottawa, has not been mined since 1873. Drillings in 1951 indicated substantial deposits of ore (concentrating grade) consisting of magnetite with varying amounts of hematite, pyrites, and mica. Preparation is necessary to lower the rather high sulphur content.—A. G.

The General Geology of Eyre Peninsula. R. L. Jack. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 199–215). In the section on Economic Minerals, it is shown that the best deposits of iron ore are located in the Middleback Ranges, South Australia.—J. C. B.

Ferrous Chamosite and Ferric Chamosite. G. W. Brindley and R. F. Youell. (*Mineralogical Mag. and J. Mineralogical Soc.*, 1953, **30**, Mar., 57–70). A report is given of an investigation into the crystallographic properties of ferrous and ferric Chamosite, their formation and decomposition.—B. G. B.

ORES—MINING AND TREATMENT

The Great Quebec-Labrador Venture. E. C. Allingham. (*Canad. Min. Met. Bull.*, 1953, **46**, Jan., 1–9). The Iron Ore Company of Canada's exploitation of ore resources in New Quebec and Labrador is outlined. The project aims to be delivering ore by 1954, eventually at a rate of 10,000,000 tons per season.—T. E. D.

An Iron Ore Project in Canada. (*Engineer*, 1952, **195**, Mar. 13, 399–401). A project for the exploitation of ore in Labrador and Quebec is described. The ore, found in the Labrador Trough, is intended primarily for consumption in the U.S.A. An annual production of 10,000,000 tons is envisaged and the works involved include 362 miles of railway, an ore handling plant and quay, a transfer dock, three new towns, and hydro-electric power developments.—J. McK.

The Swedish Ore Mines and Mining Methods. H. Prause. (*Z. Erz. u. Met.*, 1952, **5**, Sept., 354–363). The geographical location of the mining districts in Sweden are described in relation to the available water power. The geology of the three most important regions is given. The development of the working methods in the mining industry over the past decade is described.—R. J. W.

Mining in South Baden. G. Albiez. (*Z. Erz. u. Met.*, 1952, **5**, Sept., 341–343). A review is given of the old and modern mines in South Baden.—R. J. W.

Belt Conveyors, Arteries of New Ore Dock. W. H. Raff. (*Iron Age*, 1952, **170**, Dec. 18, 133–136). Details of the expansion of the ore unloading pier at Baltimore of the Canton Co. are given. A third crane has been added and all ore is handled by conveyors capable of moving 3000 tons/hr. Weighing is automatic and the bins and feeders can be quickly adjusted to handle different types of ore and all types of railway wagon.—A. M. F.

The Influence of the Condition of Ore Deposits on the Sampling. H. Borchert. (*Z. Erz. u. Met.*, 1952, **5**, Aug., 297–303). After some initial considerations of sampling in general, the errors incurred due to limitations of the collecting of single fragments are enumerated. The necessity for cross-section samples right through the total thickness of a deposit and for the requisite number of sampling points is described. Examples are given for the sampling in different types of deposit.—R. J. W.

Problems of Sampling Ores and Concentrates. F. Marr. (*Z. Erz. u. Met.*, 1952, **5**, Oct., 395–400). The sampling of lumpy ore and fine concentrates is considered with special reference to the sampling procedure and the size of sample.

Modern Implements for Sampling. O. Kohlmeier. (*Z. Erz. u. Met.*, 1953, **6**, Feb., 53–56). Various types of apparatus and instruments are described which have proved useful for sampling and for separating the constituents for samples. Modifications of these instruments can be made for each individual application. Such apparatus has a sieving ball mill, a pan grinder, and a mortar mill; a modern efficient boring machine is illustrated.—R. J. W.

A Simple Formula for Evaluating Iron Ores. F. H. Crockard. (*Blast Furn. Steel Plant*, 1953, **41**, Mar., 295–301). The author derives a formula which enables the value of an iron ore to be calculated from knowledge of the iron and acid (or basic) contents. Variations in the analysis of iron ores charged into a furnace are compared with the cost of operating a furnace on a standard burden.—B. G. B.

Fundamental Aspects of Grinding. E. L. Piret. (*Chem. Eng. Prog.*, 1953, **49**, Feb., 56–63). The methods of recording screen analyses are surveyed. Energy requirement, calculations, and the correlations derived from laboratory results are fully discussed. The effect of temperature on crushing is mentioned, and an empirical correlation between Mohs hardness, specific gravity, and crushing resistance is quoted.

Types of Grinding Mills and When to Use Them. H. W. Erickson. (*Chem. Eng. Prog.*, 1953, **49**, Feb., 63–68). The choice of grinding equipment, and the scope of a particular type of plant are discussed. The various types are included under revolving mills (including ball and rod mills), impact pulverizers, and attrition mills. Energy consumed for a given reduction does not depend on the type of mill, but, in

general, slow speed mills are more practical and economical in maintenance on abrasive materials.—T. E. D.

Sedimentation Analysis of Magnetite. P. G. Meerman and H. J. Odekerken. (*Fuel*, 1953, **32**, Jan., 62–66). The usual methods of sedimentation analysis are not suitable in the case of magnetite because of its magnetic properties, as a result of which it is impossible to achieve a proper dispersion of the particles. If the material is first oxidized in air, the analysis can be performed satisfactorily.—B. G. B.

Investigations on the Charging Capacity of New Kinds of Crushing Machines for the Beneficiation of Siegerland Spathic Iron Ore. E. Meinecke. (*Z. Erz. u. Met.*, 1952, **5**, Aug., 314–319). The problems of crushing are enumerated and some crushing tests on spathic ores with jaw and hammer crushers are described, the economics of the methods being compared.—R. A. R.

Investigation of Iron Sulphide Deposits in South-Central Aitkin County and Carlton County, Minn. J. Pennington and V. C. Davis. (*U.S. Bureau Mines Rep. Invest.* 4937, 1953, Jan.). A report is given of an investigation into the possible development of deposits of iron sulphide. The results of ore dressing tests are given and it is concluded that the concentrates produced by flotation treatment would be a good source of sulphur, and, that because of the low amount of silica present a high-grade iron oxide residue would be made available after the sulphur has been recovered from the concentrates.—B. G. B.

Big New Plants Highlight Beneficiation Development. E. H. Crabtree. (*Min. Eng.*, 1953, **5**, Feb., 156–161). American developments and trends in 1952 are described, concerning ore grinding, concentration, flotation, separation, handling, screening, sintering, and new chemical processes. Iron, copper, lead, zinc, manganese, vanadium and uranium ores are specially mentioned. Iron ore developments include pilot and production plants for taconite concentration, pelletizing, cyclone classifying, flotation, and heavy media separation.

Heat Hardening of Pellets Made from Taconite Concentrates. G. V. Woody. (*Blast Furn. Steel Plant*, 1953, **41**, Mar., 314–317). A description is given of a pilot plant for the hardening of pellets produced from taconite concentrates. The heating is carried out on a unit with moving pallets, similar to a sintering machine. The results obtained are of a preliminary nature and indicate that the process is suitable.—B. G. B.

Reserve Mining Company Building Large Plant to Process Taconite. C. Longenecker. (*Blast Furn. Steel Plant*, 1953, **41**, Feb., 189–191). Brief details are given of a plant which is being constructed to develop the abundant supplies of taconite in northern Minnesota. The beneficiation process involves crushing, fine grinding, magnetic separation and agglomeration of the fine concentrates into pellets. The first unit is expected to be completed in 1955 and to have an annual output of 2,500,000 tons of pellets.—B. G. B.

Permeability Tests on Blast-Furnace Raw Materials. E. W. Nixon and F. R. Maw. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 331–335.) [This issue.]

Fluidization of Masses of Particles. R. H. Wilhelm. (*Ohio State Univ. Studies, Eng. Series, Exp. Station Bull. No.* 149, 1952, **21**, Sept., 379–388). Evidence is given of the thermodynamic properties in fluidized beds, such as surface tension or internal pressure, vapour pressure and viscosity. Alternate or complementary approaches to the theory of fluidization, including consideration of a fluidized bed as a non-ideal fluid, as a system in random motion, and as a rheological system are discussed.—J. C. B.

FUEL—PREPARATION, PROPERTIES, AND USES

The Pressure Inside a Flame and Its Significance for the Ignition of Gaseous and Solid Fuels. H. Mache. (*Radex Rundschau*, 1949, No. 6, Oct., 199–207). The formation, properties, and behaviour of the cone of combustion of a bunsen flame are described and the existence of a back pressure below the flame is discussed. The mechanism and progress of ignition over the surface of the fuel is elucidated and the effect of air currents is considered.—E. C.

Effect of Pressure on the Fundamental Burning Velocity in Gaseous Mixtures. N. Manson. (*Fuel*, 1953, **32**, Apr., 186–195). The author, after proposing a theory of flame propagation, derives the following expression for the effect of pressure (p) on the burning velocity (v), $v = v_0(p_0/p)^n$ where v and v_0 are the velocities at pressures p and p_0 (normal) respectively. For rich and stoichiometric mixtures of hydrocarbons with air $n = 0{\cdot}25$, and for lean mixtures $n = 0{\cdot}3$–$0{\cdot}4$.—B. G. B.

Problems Relating to the Combustion Potential of Some Industrial Gases. L. Gagnaire. (*Mét. Constr. Mécan.*, 1952, **84**, Nov., 853–859). A number of industrial gases, produced by the combustion of some form of carbon (*e.g.*, coke or anthracite) are compared with respect to the heat required for their production and the heat produced by their combustion.—B. G. B.

Applied Thermodynamics—An Introductory Note. F. E. Simon. (*Research*, 1953, **6**, Feb., 51–53). It is not generally realized that many economic difficulties, particularly concerning use of fuel, are problems of applied thermodynamics. Without adequate understanding of the fundamentals, the most satisfactory solutions cannot be reached. The role which thermodynamics plays, or could play in modern technology, is briefly reviewed.—K. E. J.

Industrial Thermodynamics. W. R. Hawthorne. (*Research*, 1953, **6**, Mar., 119–123). The present fuel situation is marked by slowness in applying existing knowledge to reduce consumption. Consumers could greatly reduce demands for coal and oil by applying suitable familiar techniques, at some capital outlay. Economic factors involved in the use of more efficient heat exchangers and other fuel saving appliances are discussed. There is room for further application of thermodynamical knowledge, and need for improved, cheaper equipment and more fuel engineers.—K. E. J.

Theoretical Treatment of Combustion in Fuel Beds. I—Gas Composition and Heat Release. R. S. Silver. (*Fuel*, 1953, **32**, Apr., 121–137). A mathematical investigation into the combustion of fuel in a bed has been conducted. Equations are derived for the proportions of CO_2, CO and oxygen at any point in a burning bed, and for the evolution of heat in the bed. A number of the theoretical results derived are compared with experimental data and discussed.—B. G. B.

Theoretical Treatment of Combustion in Fuel Beds. II—Temperature Attained in Combustion. R. S. Silver. (*Fuel*, 1953, **32**, Apr., 138–150). Equations are derived for the calculations of fuel surface and gas temperatures. A theory of ignition temperature for the fire bed is given. The conditions necessary for a stable fire in a metal melting furnace are among the practical items considered.—B. G. B.

Radiation Heat Transfer. G. A. E. Godsave. (*Fuel*, 1953, **32**, Apr., 196–198). Certain results are presented relating to the general case of interchange of radiation between surfaces that may partly transmit as well as partly absorb and reflect the incident radiation. The surfaces are also considered to be selective emitters. Expressions are presented for calculating the radiant heat transfer under these conditions for a number of geometric configurations.—B. G. B.

Flame Velocities in Carbon-Monoxide–Oxygen Mixtures. T. W. Price and J. H. Potter. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, Jan., 91–96). Details are given of the determination of flame velocities in CO–oxygen mixtures saturated with water vapour. These velocities were found to increase with increase of initial mixture temperature.—D. H.

Carbon Particle Formation in a Gaseous Fuel. F. M. Comerford. (*Fuel*, 1953, **32**, Jan., 67–76). Propane was passed through an electric tube furnace and subjected to controlled soot-forming conditions by variation of temperature and aeration. The emissivity (in the visible spectrum) of a 1 cm. thick layer of soot-bearing gas was found to increase rapidly with temperature above 950° C. reaching 0·9 at 1100° C. for a heating time of 1 sec. A higher temperature was required to produce the same emissivity in less time.

Problems in the Control of Dust from Coal-Fired Boiler Furnaces. E. R. Kaiser. (*Ohio State Univ. Studies Eng. Series, Exp. Station Bull. No.* 149, 1952, **21**, Sept., 389–399). A brief description of the combustion process and the formation of porous hollow cinders, beads of ash, and other heterogeneous dust particles is given. The effects of particle density and gas temperature on the terminal velocities of the minute particles of coal, cinder, and fly ash in the furnace, dust collector, and atmosphere are explained. An interim method of determining particle density for sized mixtures of porous, spherical, and non-spherical dusts is suggested to replace the specific gravity determination now used.—J. C. B.

Combustion Safeguard Equipment. J. Price. (*Indust. Gas*, 1952, **16**, Oct., 14–18; Nov., 56–60; Dec., 80–86). Details are given of the indirect application of safeguard equipment to single gas burners where gas rates in excess of 750 cu. ft./hr.

are used. Three systems employing a thermo-electric device are described and details are given of systems for protection in case of flame failure.—D. H.

Developments in Steam Generation. F. X. Gilg. (*Blast Furn. Steel Plant*, 1953, **41**, Jan., 98–102; Feb., 220–223). A number of examples of modern steam boiler design are given and the operating characteristics are discussed.—B. G. B.

Central Control Rooms for Modern Boiler Plants. L. Walter. (*Steam Eng.*, 1953, **22**, Feb., 164–169). The general design and layout of control rooms in chemical plants, steelworks, power stations, and oil refineries are outlined.—T. E. D.

Fuel Saving—Heat Economy in Furnace and Forge Plants. C. S. Darling. (*Iron Steel*, 1953, **26**, Feb., 44). The author summarizes methods which individually or collectively will aid in the saving of fuel. The main reference is to oil-fired plant, but many of the methods are also applicable to coal and gas firing.—G. F.

Heat Conduction in Solids as an Eigenvalue Problem. G. D. Wassermann. (*Quart. J. Mech., Appl. Math.*, 1952, **5**, Dec., 466–471). Problems of linear heat conduction in solids are formulated as 'eigenvalue' problems. Assuming that: (1) The thermal properties are independent of temperature; (2) the boundary conditions are independent of the temperature; and (3) that no change of phase or state occurs in the temperature range considered, the standard problems can be rapidly solved.—J. C. B.

The Calculation of the Efficiency of Heat Regenerators. D. N. de G. Allen. (*Quart. J. Mech. Appl. Math.*, 1952, **5**, Dec., 455–461). The calculation of the efficiency (or thermal ratio) of a heat regenerator requires essentially the solution of a pair of simultaneous first-order partial differential equations in order to determine the temperatures of the fluid and of the matrix throughout one cycle of operation. A method is proposed.

Sampling and Preparing Samples of Solid Fuels. E. Frei. (*Z. Erz. u. Met.*, 1953, **6**, Feb., 56–66). A brief review of the literature leads to a description of the present state of standardization in this field. The basis for a sampling technique is described and the carrying out thereof detailed. Automatic sampling, the use of a paddle, and the sampling of a static mass are illustrated for different coals. The conversion of a crude sample into a laboratory sample is also described.—R. J. W.

Assessment of the Mineral Species Associated with Coal. J. B. Nelson. (*Brit. Coal Utilisation Res. Assoc., Monthly Bull.*, 1953, **17**, Feb., 41–55).

Chemical Significance of the True Density of Coals. I. G. C. Dryden. (*Fuel*, 1953, **32**, Jan., 82–87). By applying an (approximate) additive law of atomic volumes to the calculation of the densities of coals, D. W. van Krevelen has obtained values of a 'ring condensation index' in the coal series. The author reviews this treatment, examines the values obtained and draws some fresh conclusions.—B. G. B.

Factors Influencing the Design of Coal Preparation Plant. W. H. Griffiths. (*South Wales Inst. Eng.* Mar. 19 1953, Preprint). It is very important to carry out a complete examination of the raw coals to be treated before designing the plant. The effect which variations in coal composition have on the design of the plant is considered in detail. The influence which marketing requirements has upon the layout of the plant is stressed.—B. G. B.

Coal Preparation Policy, with Special Reference to Northumberland and Durham. F. F. Ridley and W. J. Charlton. (*Trans. Inst. Min. Eng.*, 1953, **112**, Mar., 440–464). The paper reviews the field of coal preparation in relation to mining conditions and national coal consumption during the next 15 years.—J. C. B.

Grinding Experiments with a Fuller-Peters Mill. H. Winter and A. Flamm. (*BWK*, 1953, **5**, Feb., 45–49). In connection with research on the firing of coke breeze and coal dust, the grinding of coke has been investigated. An analysis is made of the performance of the Fuller mill and its ancilliary equipment.—P. F.

Plastic Properties of Coking Coals. J. Bronowski, D. Fitzgerald, D. W. Gillings, and D. C. Rhys-Jones. (*Nature*, 1953, **171**, Feb. 28, 389–390). An equation is derived relating the viscosity of a coal above 400° C. to the velocity constant of the decomposition reaction producing an infusible solid. Predictions have been verified for four different coals and a calculation of activation energy gives a figure in agreement with that quoted for the energy necessary to break the carbon–carbon bond in the decomposition of mineral oils.

New Plant for High-Grade Coke Production. A. E. Edge. (*Optima*, 1953, **3**, No. 1, 29–33). A large new coking plant, incorporating several unusual features, has been constructed near Vryheid, in Natal, to meet the growing demand for metallurgical coke, including the essential needs of the South African steelmaking industry. The features of the plant are described.—J. C. B.

Forty Years of the Coke-Oven Committee. H. Krueger. (*Stahl u. Eisen*, 1953, **73**, Mar. 26, 389–394). The establishment and development of the Coke-Oven Committee and the problems it has tackled are described, particular attention being paid to the personalities who have guided its work and to whom its successes are due. The way in which improvement in coke quality, the utilization of gases and by-product recovery can ensure economic future working of coke ovens is discussed.—J. P.

Cost Accounting in Carbonisation Practice. (*Coke Gas*, 1953, **15**, Mar., 102–104). Cost accounting in by-product coke-oven plants is discussed and the methods used by Republic Steel Corporation are outlined. The advantages of such a detailed examination of costs are emphasized.—T. E. D.

Design of Cyclone Gas Cleaners. F. Magyar and F. Schulz. (*Radex Rundschau*, 1949, No. 7, 262–269). Data required for the calculation of cyclones are discussed and nomograms are constructed. A cyclone coefficient is evolved and its relation to number and size of cyclones, critical grain size and degree of extraction is shown.—E. C.

The Generation of High Quality Producer Gas. H. Barret. (*Radex Rundschau*, 1949, No. 7, Nov., 270–277). [In German and French]. A description is given of experiments carried out at the steelworks of Aciérie et Forges de Firminy, France, aiming at an improved producer gas for open-hearth furnaces. Improvements were achieved through the use of oxygen-rich coal which reduced air requirements for combustion, and through the avoidance of chanelling in the bed by using even-sized, non-caking fuel having a non-fusing ash. Other factors which improved the producer gas were the maintenance of high combustion temperatures, correct grate loading, use of rotary blowers for air feed, and automatic controls.—E. C.

TEMPERATURE MEASUREMENT AND CONTROL

Advances, Importance, and Effect of Temperature Measurement in Iron and Steel Works. K. Guthmann. (*Radex Rundschau*, 1951, No. 5, Sept., 211–223). Progress and development of pyrometry in the iron and steel industry during the last ten years are described and discussed. Various types of pyrometers are considered and their uses are illustrated by practical examples and research results.—E. C.

High-Temperature Immersion Thermocouples. E. T. Myskowski and H. F. Bishop. (*Amer. Foundryman*, 1953, **23**, Apr., 150–155). The authors report how the Naval Research Laboratory has overcome the difficulties of using thermocouples for molten metals above 2100° F., their refinements in technique, and precautions which should be observed for maximum accuracy.—L. E. W.

A Small Combustion Chamber for Flame Temperature Measurements Under Reduced Pressure. V. E. Henny. (*Fuel*, 1953, **32**, Jan., 36–38). A combustion chamber, suitable for optical methods of flame temperature measurement up to 1800° C. and at pressures from 0 to 2 atm., is described. The windows of the chamber can be replaced in 5 min.—B. G. B.

Instrumentation. R. H. Munch. (*Indust. Eng. Chem.*, 1952, **44**, Dec., 77A–80A). Factors influencing the reproducibility of electronic continuous balance potentiometer pyrometers are their installation, maintenance, adjustment, range, and ageing of the cells and other components. Means of compensation for various types of instrument are described. Optimum reproducibility is ensured by careful attention to thermocouple leads, location of the instrument, calibration, and the level of amplifier sensitivity.—K. E. J.

REFRACTORY MATERIALS

The Heat Balance of Calcining Kilns for Cement, Lime, Magnesite, and Dolomite. W. Anselm. (*Radex Rundschau*, 1950, No. 1, Jan., 3–61). A comprehensive treatise in general terms and with specific examples is given, examining all factors relating to the assessment of through-put and heat consumption of kilns. An outline of fundamental

principles, experimental methods, sample log sheets, and tables of data are quoted to form a complete guide for calculations of heat balances and performance, check of heat losses, and to permit standardization of the methods of furnace assessment.—E. C.

The Mechanism of the Caustic Burning of Magnesite in Air, in a Vacuum, and in Various Gases. F. Bischoff. (*Radex Rundschau*, 1950, No. 3, May, 141–147).

Using Waste Heat in the Heavy Clay Industry. E. Rowden. (*Trans. Brit. Ceram. Soc.*, 1953, **52**, Feb., 69–102). Methods of using waste heat from intermittent and from continuous kilns are dealt with in detail; reference is also made to the recovery of waste heat from steam plants. The heat balance for intermittent kiln firing of silica bricks and using coal as heat source is given.—E. C. S.

Dolomite in the Steel Industry. Part I. The Development and Working of Dolomite Quarry at Ardrossan. J. Hammer. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 61–69). A short history of dolomite quarrying in Australia is given, and the quarrying, crushing, and shipping of the stone at Ardrossan is described. South Australia is considered in more detail. Although small sections have given up to 4% SiO_2, the average grade has been established at 1% SiO_2.—J. C. B.

Dolomite in the Steel Industry. Part II. The Place of Dolomite in Steel Making. T. Mann. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 69–90). The processing and uses of the various forms of dolomite in the steel industry are considered, with particular reference to Australian practice. A definition of terms used for the various products obtained by burning dolomite is followed by a discussion of the chemistry and quality of the product aimed at. A review of burning equipment used in England, America, and Australia is given with a detailed account of that at Newcastle, N.S.W. The uses in the steel-making furnaces are detailed, pointing out that the future policy for open-hearth furnaces will be to use dead-burned magnesite for the new hearths with rotary-calcined dolomite (at 1600° C.) or magnesite cements for repairs.—J. C. B.

Two New Crystalline Phases of the Anorthite Composition $CaO.Al_2O_3.2SiO_2$. G. L. Davis and O. F. Tuttle. (*American Journal of Science Bowen Volume*, 1952, Part 1, 107–114). Two new crystalline phases of the composition $CaAl_2Si_2O_8$ are described, giving the optical properties and X-ray powder diffraction data. Their synthesis and stability are discussed. Comparisons are drawn with similar modifications of $BaAl_2Si_2O_8$.—J. C. B.

Significance of Variation in the High–Low Inversion of Quartz. M. L. Keith and O. F. Tuttle. (*American Journal of Science Bowen Volume*, 1952, Part 1, 203–280). The high-low inversion of quartz has been studied for about 250 quartz specimens by a differential thermal method. For over 95% of the natural specimens the inversion temperatures were within a range of 2·5° C., but for synthetic samples they varied as much as 160° C. depending upon the method of growth, and the temperature. A 'finger print' method is suggested for comparing quartz from various sources and for the study of zoning within rock bodies.—J. C. B.

A Reconnaissance of Liquidus Relations in the System $K_2O.2SiO_2$–FeO–SiO_2. E. Roedder. (*American Journal of Science Bowen Volume*, 1952, Part 2, 435–456). A reconnaissance has been made of that portion of the system K_2O–FeO–SiO_2 having K_2O/SiO_2 ratios greater than 1:2. The results on 62 compositions are presented as a preliminary phase diagram for the condensed system $K_2O.2SiO_2$–FeO–SiO_2 representing liquidus relations in equilibrium with metallic iron under 1 atm. pressure of pure nitrogen. Two new compounds $K_2O.FeO.3SiO_2$ and $K_2O.FeO.5SiO_2$ were found and their relationships to equivalent compounds in the systems K_2O–Al_2O_3–SiO_2 and K_2O–MgO–SiO_2 discussed.

The System FeO–Al_2O_3–SiO_2. J. F. Schairer and K. Yagi. (*American Journal of Science Bowen Volume*, 1952, Part 2, 471–512). Phase-equilibrium studies of this system, at and just below temperatures where a liquid phase is present, show one ternary compound, the iron anologue of cordierite ($2FeO.2Al_2O_3.5SiO_2$), which decomposes at 1210° ± 10° C. to mullite, tridymite, and liquid. The fields of stability of corundum, mullite, hercynite, iron cordierite, cristobalite, tridymite, fayalite, and wüstite have been delineated. Seven invariant points were located. Iron cordierite crystallizes with some reluctance, and the metastable invariant points fayalite + tridymite + spinel + liquid at 1073° C.± 5° C., and mullite + hercynite + tridymite + liquid at 1205° ± 10° C. can be realized. No ferrosilite or almandine garnet could be crystallized from the melts at any temperature even when melts were seeded with these crystalline phases.—J. C. B.

Progress Report on the System Cr_2O_3–FeO–SiO_2. R. Zoja. (*Radex Rundschau*, 1950, No. 5, Oct., 207–214). A detailed description is given of the method of preparing specimens by oxy-acetylene fusion, and of the examination of the samples in reflected polarized light and with dark ground illumination. The constituents and structures of the binary and ternary systems are described and discussed, and supplemented by colour photomicrographs.—E. C.

Catalytic Surface Activity of Burnt Magnesite. E. Cremer and E. Kullich. (*Radex Rundschau*, 1950, No. 4, Aug., 176–179). Surface properties and catalytic effects of MgO are shown to be related to the maximum calcining temperature. A series of experiments utilizing the decomposition of formic acid is applied to investigate the activity of MgO fired at temperatures ranging from 370° to 900° C.—E. C.

Calorimetric Studies of Active Magnesium Oxide Produced from Natural Magnesite. W. Treffner. (*Radex Rundschau*, 1950, No. 2, Mar., 125–131). The preparation of active magnesia products from natural magnesite by low temperature burning is described, also the use of an adiabatic integrating calorimeter for prolonged measurements of heat evolved during the hydration of caustic magnesia. Kinetics and the mechanism of the reaction are discussed.—E. C.

The Development of Thermal Shock Resisting Magnesite and Chrome-Magnesite Refractories. J. Berlek. (*Radex Rundschau*, 1950, No. 2, Mar., 85–90). The problems of manufacturing magnesite bricks resistant to thermal shock are discussed. Research and development work carried out at the Radenthein works, which led to the production of the Radex refractories, are described.—E. C.

Kinetics of the Thermal Decomposition of Magnesite. E. Cremer and F. Gatt. (*Radex Rundschau*, 1949, No. 7, 257–261). Kinetic measurements concerning the thermal decomposition of natural magnesium carbonate are given. Tests were carried out at various temperatures with various size fractions. Differences in grain size and surface area did not affect the speed of decomposition. The effective speed-controlling factor is a process of diffusion which is related to the primary particle size and is dependent on temperature.

Investigations of the Reaction Products Formed at the Contact Surface Between Liquid Steel and Fireclay Brick. T. Wahlberg and L. Fredholm. (*Jernkontorets Ann.*, 1953, **137**, 1, 1–26). [In Swedish]. Reaction products formed at the interface between liquid steel and fireclay brick were isolated and investigated. Analyses showed that erosion by the steel was caused by a reaction between manganese in the steel and silica in the brick, manganous oxide and silicon being formed. The manganous oxide dissolves the brick and leads to the formation of manganese-aluminium-silicate. Mullite is formed at the interface, preferentially at the surface of the grog grains; none is formed in contact with the quartz grains.—G. G. K.

Cast Refractories Replace Brick in Heating Furnaces. W. G. Patton. (*Iron Age*, 1952, **170**, Dec. 18, 140–141). Tests on an unspecified cast refractory material as a substitute for brick refractory in a barrel-shaped forging furnace have shown comparative freedom from spalling, longer furnace life, and a substantial reduction in maintenance costs.—A. M. F.

Further Investigations on the Sintering of Oxides. P. W. Clark, J. H. Cannon, and J. White. (*Trans. Brit. Ceram. Soc.*, 1953, **52**, Jan., 1–49). The isothermal shrinkage curves of MgO, CaO, Fe_2O_3, and copper were determined at various temperatures. The sintering of Fe_2O_3 proceeded at a relatively low temperature but it is not possible to say with certainty whether it actually began below the Tammann temperature. It is, however, probably above that of Fe_3O_4 (1594° C.).

Specifications for Refractories. H. M. Glass. (*Claycraft*, 1952, **26**, Dec., 110–119). The author presents a guide to principal basic shapes, performance tests, and the requirements of a national standard.—E. C. S.

Spalling of Fire-Clay Brick. G. R. Eusner and W. S. Debenham. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Dec., 489–492). A description is given of panel spalling test equipment which incorporates new automatic features and temperature controls. The spalling characteristics of many high-duty and super-duty refractories, as determined with this equipment, are discussed.—E. C. S.

A Comparison of Gas-Fired Pyrometric Cone Equivalent Furnaces. H. F. Smalley and R. B. Soseman. (*Bull. Amer. Ceram. Soc.*, 1953, **32**, Jan., 5–11). Pyrometric cone equivalent tests on various refractory materials showed unsatisfactory agreement in two different furnaces until a fuel gas mixing device was installed.—E. C. S.

Operational Results with Ladle Fireclay Bricks of Different Types when Teeming Open-Hearth Mild Steel. K.-O. Zimmer. (*Stahl u. Eisen*, 1953, **73**, Mar. 26, 411–415). Operational data on 17 different types of ladle brick are compared with laboratory results in an endeavour to reduce consumption and cost of relining by choice of a suitable type. It is shown that surface finish, cold compression strength, softening range under load, and porosity are criteria of the quality of fireclay ladle bricks. As a result of the tests it was possible to reduce consumption from about 8 to 5·8 kg./ton and costs from DM 1.50 to DM 0.94/ton.—J. P.

Going to Try a Basic Lining ? Here's a Guide for Refractory Selection. J. P. Holt. (*Amer. Foundryman*, 1952, **22**, Nov., 63–68, 102). The author considers in turn the various forms of magnesia, lime, and spinel mineral chromite refractories. The application of linings, and the chemical reactions to which the refractories are subjected are both described. Both monolithic, and brick linings are dealt with.—E. T. L.

Refractories for the Basic Open-Hearth Furnace and Auxiliary Equipment. E. B. Snyder. (*Indust. Heating*, 1952, **19**, Oct., 1929–1934, 1988; Nov., 2149–2152, 2156; Dec., 2362–2366). The types of refractory used in the flues, checker chambers and furnace ends are first described, and the development of high-temperature concrete for flues is discussed. Refractories used in the furnace body are considered and the development of super-duty silica brick and the zebra construction (alternate rings of basic and silica brick) for roofs is described. Refractories for hot metal mixers and ladles are also discussed.—B. G. B.

Refractories and the North-East Coast. W. W. Stevenson. (*Refract. J.*, 1952, **28**, Dec., 539–549). Details of practical experience in the applications of refractories in: (1) Ladle bricks and jointing; (2) checkers; (3) blast-furnaces; (4) open-hearth furnace roofs, hearths, back walls, and front pillars are considered. A direct method of cutting cost of refractories per ton of steel is to increase the tons per hour produced by any given furnace, *e.g.*, by changing from gas to oil-firing.

Silicon Carbide Heating Elements—Development, Uses, Chemical and Physical Investigations. T. H. Elmer. (*Bull. Amer. Ceram. Soc.*, 1953, **32**, Jan., 23–27). Chemical and physical investigations were carried out on resistors composed essentially of recrystallized silicon carbide. An explanation of the failure of silicon carbide heating elements at high temperatures is offered. By maintaining the elements at above 600° C., even when not in use, stresses due to differences in expansion between silicon carbide and silica are reduced.

Manufacture, Properties and Uses of the Insulating Material 'Vermiculite.' H. Kramer. (*Stahl u. Eisen*, 1953, **73**, Feb. 12, 225–227). Vermiculite is made by heating mica so that the combined water between the individual layers is driven off, thus expanding the whole structure and giving a light-weight material. This is an excellent heat and sound insulator and many of its uses are described, both as a loose filling and in the form of porous concrete or plaster.—J. P.

Thermal Conductivity and Insulation. (*Ceramics*, 1953, **4**, Feb., 536–544). The insulating properties of some common refractories are discussed.—E. C. S.

The Thermal Conductivity of Some Polycrystalline Solids at Low Temperatures. R. Berman. (*Proc. Phys. Soc.*, 1952, A, **65**, Dec. 1, 1029–1040). Thermal conductivities of alumina, beryllia, and graphite were determined between 2° K. and room temperature. The electronic contribution to heat conduction is very small. The phonon mean free path is limited by scattering at crystallite boundaries at low temperature, and does not exceed the crystallite size in graphite. Graphite specimens with small crystallites are therefore extremely good insulators at low temperature, being better than glass at $< 10°$ K. (14 references).—K. E. J.

Fundamentals of Foundry Refractories. J. D. Custer and J. S. McDowell. (*Trans. Amer. Found. Soc.*, 1952, **60**, 681–686). The melting points and other properties of various refractories in use in the foundry are given. The uses of fireclay, high-alumina, silica, and basic bricks in foundry practice are described; ganister-fireclay mixes and hydraulic setting castable refractories are also considered.—J.McK.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Developments in Blast-Furnace Design. S. K. Nanavati and P. K. Chatterjee. (*Trans. Indian Inst. Met.*, 1951, **5**, 23–50). A general resumé is made of the early history of blast-furnace design and operation. The authors explain each phase of the development.—D. H.

Blast-Furnace Model Experiments. S. Traustel. (*Radex Rundschau*, 1950, No. 3, May, 135–140). The author discusses the applicability and competence of model experiments for the study of processes which involve chemical reactions. Principles of model laws are considered. The application of model experiments and laws to blast-furnace problems is described.—E. C.

Ironmaking: A Review of Progress in the Process, 1939–1952. J. Taylor. (*Iron Steel*, 1953, **26**, Feb., 39–43; Mar., 87–90; Apr., 122–127; May, 155–160). The author critically reviews progress made in connection with ironmaking during the period 1939–1952. The chief topics discussed include the operating conditions in the blast-furnace, the energy balance, the theory of the operation and factors governing its efficiency, and the thermodynamics and rates of the gas–solid and slag–metal reactions in the furnace. Reference is also made to modifications of the standard process, including high top pressure, the electric furnace, oxygen-enriched blast, and the low-shaft furnace.—G. F.

Towards More Pig Iron—Cargo Fleet New No. 1 Blast Furnace. (*Iron Steel*, 1953, **26**, Mar., 81–86; Apr., 129–133). Following a brief account of the layout of the works of the Cargo Fleet Iron Co., Ltd., details are given of the construction and design of the new No. 1 blast-furnace, together with its charging equipment and controls, the electrical equipment, the blast and water systems, the cast house, and dust-catcher.

Saving of Coke in the Blast-Furnace by Varying Temperature and Composition of the Blast. O. Hájíček. (*Hutník* (Prague), 1953, **3**, 2, 30–34). [In Czech]. An analysis of the possibilities of improving the efficiency of blast-furnace performance, dealing primarily with the blast, is given. The principal points considered are: (*a*) Dependence of coke consumption on the blast temperature. (*b*) The use of oxygen-enriched blast. This method promotes the reduction of silica, makes it easier to melt calcium-rich slags, and reduces the coke rate 10%. The power requirements for the production of oxygen of various degrees of purity are given. (*c*) Drying the blast. Current methods are evaluated and the thermal balance of the processes is shown diagrammatically. (*d*) Finally, the effects of raising the pressures of the blast and the blast-furnace gas are surveyed, and the modifications in the design of valves and blast-furnace accessories, thereby necessitated, are examined.—P. F.

Crucible Expansion Well Under Way. (*Iron Steel Eng.*, 1953, **30**, Jan., 164–167). A brief description is given of the new 25-ft. hearth blast-furnace of the Crucible Steel Company of America. Details are given of the turbo-blowers, the hoist control and instrument room, storage facilities, skip cars, dust catchers, gas washer and precipitators.—M. D. J. B.

Water Failures on Blast Furnaces. H. Goldfein. (*Blast Furn. Steel Plant*, 1953, **41**, Feb., 209–212). The practical measures to be taken when a failure in the water supply to a blast-furnace occurs are considered. Examples of water failure on American furnaces are discussed and details are given of the steps taken to minimize damage.—B. G. B.

Further Information on High Top Pressure. I. Lockerbie. (*West Scotland Iron Steel Inst. Advance Copy*, 1953). In 1950, No. 2 Furnace at Clyde Iron Works was converted to operate at high top pressure. Earlier papers described the engineering work and examined the coke consumption and operating results relating to a similar furnace operating normally. Later operating data show no difficulties in maintenance and confirm the greater output obtainable.—P. C. P.

Modern Disintegrator Gas Cleaning. G. Baumann. (*Stahl u. Eisen*, 1953, **73**, Apr. 9, 492–494). After discussing the original and the reconstructed gas cleaning plant at the August-Thyssen-Hütte, Hamborn, the alteration of the packed tower to a spray cooler is described. This change resulted in a reduction of pressure loss in the cooler from 60 mm. to 10 mm. water pressure. The constructional improvements during the installation of the disintegrators

are discussed and operational results are reported. There was a reduction in the dust content from 20–24 to 8–10 mg./cu. m. while the current consumption of the disintegrators fell by 1 kWH./cu. m.—J. P.

Instruments for Blast Furnace Control. P. Thierry. (*Mét. Constr. Mécan.*, 1952, **84**, Dec., 919–920). A short note on the use of instruments in blast-furnace practice is presented.

PRODUCTION OF WROUGHT IRON

The Hundred Year Old, Soon Extinct, Lancashire Process. C. W. Tideström. (*Blad. Berg. Vänner*, 1952, **30**, 21, 51–68). [In Swedish]. The adoption and gradual decline of this method of manufacturing wrought iron are outlined. Production decreased from 171,000 tons in 1900 to 5664 tons in 1948. Reasons for the decline are given.—G. G. K.

DIRECT PROCESSES

Pig Iron Smelting without Metallurgical Coke. W. E. Krebs and D. Jagat Ram. (*Trans. Indian Inst. Met.*, 1951, **5**, 51–76). A new combined rotary kiln process for the production of pig iron from ore fines and non-coking coal, embodying significant features of the Krupp-Renn process in rotary kilns and the Stürzelberg rotary furnace, is described. Recent developments in pig-iron smelting with oxygen low-shaft furnaces are discussed.—D. H.

Recent Developments in the Stürzelberger Iron Reduction Process. H. Reinfeld. (*Radex Rundschau*, 1951, No. 5, Sept., 178–187). A detailed description is given of the principle, development, and practice of this process which was evolved for dealing with pyrite roasting residues rich in zinc (8–10%). The direct reduction takes place in a short rotary drum which has a rammed tar–dolomite lining. Lime is added to produce a highly basic slag, the pyrite cinders, pre-calcined on a sinter strand, are mixed with coke breeze and fired with pulverized coal burners. The zinc is recovered from the waste gases. The drum works discontinuously in 7-hr. heats and the capacity of such plant is limited in comparison with a blast-furnace. Operation, maintenance, and economics are discussed. The product is a high-grade liquid pig iron, two drums yield 500 to 600 metric tons per month and make 1·3 to 1·4 tons of slag per ton of pig iron.

Successes and Failures in Sponge Iron Manufacture. (*Metal Bulletin*, 1953, Mar. 17, 9–12). A fairly detailed examination is made of a number of sponge iron processes which have been investigated. The principles underlying their operation and the factors which determine the cost of the final product are discussed.—B. G. B.

PRODUCTION OF STEEL

Recent Developments in the European Iron and Steel Industry. B. Matuschka. (*Radex Rundschau*, 1951, No. 5, Sept., 188–210). A wide survey is presented covering all aspects of iron and steel production, economical and technical. Pre-war developments are summarized and contrasted with post-war conditions, planning, and development. Planned increases in European production are urged also the securing of African raw materials to supplement Europe's falling reserves.—E. C.

Progress in Steelmaking Processes in America. J. S. Marsh. (*Metal Progress*, 1953, **63**, Jan., 74–77). The principal steelmaking processes are first considered. Faster melting times (for both open-hearth and electric furnaces) have increased the efficiency of the steelmaking processes. The thermal efficiency of open-hearth furnaces now reaches 40% whereas a few years ago efficiencies of 15–18% were considered satisfactory.—B. G. B.

Developments in the Iron and Steel Industry During 1952. I. E. Madsen. (*Iron Steel Eng.*, 1953, **30**, Jan., 123–161). The author gives a comprehensive review of the developments and achievements of the iron and steel industry in the U.S.A. during 1952.—M. D. J. B.

The Steelmaker's Contribution to Shipbuilding. J. B. Kelly. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 243–266). The author gives a brief account of the making and shaping of steel for shipbuilding at the Newcastle plants of the Broken Hill Proprietary Co., Ltd., Commonwealth Steel Co., Ltd., and the Port Kembla plant of Australian Iron and Steel, Ltd.—J. C. B.

Factors Influencing Surface Quality of High Sulphur Steels. G. G. Blean. (*Iron Steel Eng.*, 1953, **30**, Jan., 79–81). This paper discusses the careful steelmaking practices, correct handling, and rolling procedures essential for the production of high quality high-sulphur steel. Ingot mould conditioning, mould design, track time, heating, and rolling conditions are examined in detail.—M. D. J. B.

Steel Refining in the Runner. (*Hutník*, (Prague), 1953, **3**, 1, 9–10). [In Czech]. A simple method of reducing the gas content of steel as it passes along the runner from the taphole is described. The method, used since 1950 at the Henningsdorf steelworks, is based on the use of a covered sheet-metal runner, lined with graphite. The runner is suspended from a crane and can be used as an extension piece to the fixed runner. Oxygen and nitrogen are removed to a considerable degree as the steel flows along the covered runner which contains a reducing atmosphere because of the carbon lining. The method is particularly useful when tapping transformer steels. The watt loss of transformer steels poured by this method was about 20% below similar steels cast without this special runner.—P. F.

Developments in Alloying Elements for Steel Manufacture. H. Willners. (*Jernkontorets Ann.*, 1952, **136**, 11, 445–467). [In Swedish]. The article reviews the applications of low-carbon ferrochrome, siliconchrome, boron, and alloys containing nitrogen. The effects of cerium and lanthanum on hot working and ductility of stainless steels are described.—G. G. K.

Sampling in Metallurgical Investigations. W. Oelsen. (*Stahl u. Eisen*, 1953, **73**, Apr. 9, 495–498). Difficulties inherent in taking metal and slag samples so as to investigate conditions and compositions in the molten state at high temperatures are discussed generally.—J. P.

Some Factors Affecting Open-Hearth Steelplant Performance. J. S. Curphey. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 305–316). [This issue].

The Venturi Burner for Open-Hearth Furnaces. F. Bartu. (*Radex Rundschau*, 1950, No. 5, Oct., 243–247). The principle and construction of venturi burners are described and the classical type is compared and contrasted with a semi-venturi type developed by Maerz Ofenbau G.m.b.H. The latter is claimed to give a better performance and have a longer life.—E. C.

Investigation of the Economics of an All-Basic Lined Open-Hearth Furnace of the Maerz Type. W. Titze. (*Radex Rundschau*, 1951, No. 1, Feb., 9–12). All details relating to the installation of the all-basic lining in a Maerz type open-hearth furnace, and data and details for the whole campaign are given and compared with corresponding information for an ordinary open-hearth furnace. The Maerz furnace is claimed to show lower consumption of refractories and fuel, lower costs of maintenance, and higher efficiency.—E. C.

Some Experience with an All-Basic Tilting Furnace. J. Mitton. (*West Scotland Iron Steel Inst. Conference on All-Basic Open-Hearth Furnaces*, 1952, Paper No. 443, pp. 218–242). This paper gives operating results obtained from a 60-ton hot metal tilting furnace, oil-fired, and with basic brickwork. In a previous campaign the furnace had been operated on producer gas, also with basic brickwork. A description of the construction of the furnace is given, and the furnace life and maintenance are reviewed. Fuel consumption of this furnace was heavy, and attempts are being made to reduce this. It is concluded that, under suitable conditions, the all-basic furnace is satisfactory.—P. C. P.

Improvements in Open-Hearth Plants through the Use of Chrome–Magnesite Bricks. H. Barret. (*Radex Rundschau*, 1950, No. 5, Oct., 215–222). Preliminary trials and a gradual change-over to chrome–magnesite linings and roofs in the open-hearth furnaces of Aciéries et Forges de Firminy, France, are described. The basic lining resulted in improved performance and efficiency, but this can only be attained where working temperatures may be raised. Improvements are also achieved in dephosphorization and desulphurization.

Repair and Maintenance of Open-Hearth Furnaces in the U.S.A. R. W. Evans and I. S. Scott-Maxwell. (*J. Iron Steel Inst.*, 1953., **174**, Aug., 378–382). [This issue].

Operation and Maintenance of Open-Hearth Furnaces in Germany. A. Mund and C. Kreutzer. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 373–377). [This issue].

The Effect of Alkalies on the Checker Bricks of Open-Hearth Furnaces. N. Skalla. (*Radex Rundschau*, 1951, No. 1, Feb.,

25–28). A survey of literature together with some experimental work show that the flue dust of all-basic open-hearth furnaces may contain considerable amounts of alkali sulphates, particularly potassium, which cause severe damage to the checker bricks. The alkalies are traced to the fuel. The use of basic checker bricks is advocated as a remedy.—E. C.

Graphic Evaluation of Metallurgical Equilibria for the Practical Operation of Steel Plants. E. Plöckinger. (*Radex Rundschau*, 1950, No. 5, Oct., 223–229). A number of graphs and nomograms, derived from the distribution of alloying elements in the metal and the slag, are presented and discussed. Their practical applications are demonstrated using manganese and chromium reactions in acid and basic steelmaking processes.—E. C.

Studies in the Deoxidation of Iron: Deoxidation by Titanium. E. Ll. Evans and H. A. Sloman. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 318–324). [This issue].

The Ternary System, FeO–MnO–SiO_2. Part I. Oxide Orthosilicate Slags. P. T. Carter, A. B. Murad, and R. Hay. (*West Scotland Iron Steel Inst. Advance Copy*, 1953). The FeO–$2FeO.SiO_2$–$2MnO.SiO_2$–MnO part of the FeO–MnO–SiO_2 ternary system has been examined by thermal and microscopical methods, and the liquidus surface determined. A binary eutectic curve was found to connect the wüstite–fayalite and MnO–tephroite eutectic points.—P. C. P.

Some Practical Notes on Casting of Ingots for Seamless Tubemaking. G. Bowman. (*West Scotland Iron Steel Inst. Advance Copy*, Paper No. 449, 1953). **The Casting of Ingots for Seamless Tube Making.** G. Bowman. (*Engineering*, 1953, **175**, Feb. 27, 286–287; Mar. 20, 381–383; *Iron Coal Trades Rev.*, 1953, **166**, Feb. 27, 477–482). These notes consider the requirements for and practical difficulties of casting killed steel for use in the rotary forge tube-making process. The formation of ingot cracks is discussed, with suggestions as to causes and prevention. The effect of the pipe cavity during rolling is illustrated; ill effects can be eliminated by the use of straw for hot topping. The occurrence of blowholes and methods of prevention are described.—P. C. P.

Some Measurements on Open-Hearth Furnace Flames. G. W. Van Stein Callenfels. (*West Scotland Iron Steel Inst. Conference on All-Basic Open-Hearth Furnaces*, 1952, Paper No. 444, 243–261). Three problems arose at the Royal Netherlands Blast Furnaces and Steelworks after the war: (1) Whether to try air or steam atomization; (2) the type of burner to be chosen; and (3) the arrangement of the burners in the furnace. Air atomization on a twin-burner system of a very crude design was chosen, but later changed to high-pressure steam atomization. Work from the Flame Radiation Research Project showed more detailed differences between air and steam atomization. The original arrangement of twin burners was kept, although the furnace design and size were changed considerably: the present single-uptake design gave good production figures, although the maintenance on the end walls was found to be somewhat too high.—P. C. P.

Large South African Electric Furnace. H. J. G. Goyns. (Inst. Production Engineers: *Foundry Trade J.*, 1953, **94**, Mar. 5, 261–266). The early development of electric melting furnaces in South Africa and the present position are examined. There are now over 40 direct-arc furnaces in operation rated at 60,000 kVA with capacities up to 10 tons. Full details of a new 3000-kVA 10-ton arc furnace are given. The arc is automatically controlled by a rotary regulator, and the tilting and roof-slewing operations are hydraulic. Renewal and slipping of the electrodes are pneumatic, and water-cooling is used throughout.—L. E. W.

Stainless Steel Melting Practices Have Changed. B. R. Queneau and A. C. Ogan. (*Iron Age*, 1952, **170**, Dec. 4, 165–169). Amongst recent innovations are the use of oxygen, nickel oxide sinter, chromium pellets, and electrolytic manganese. By using ferrochromium pellets, 87–92% of the chromium passes in the metal and 3 to 4 hr. are saved in heat times when making 0·03% max. C stainless steel. The use of stainless steel scrap in making this grade is not recommended.—A. M. F.

Slagging Losses of Alloying Elements during Refining with Oxygen in the Basic Electric Furnace. E. Pachaly. (*Stahl u. Eisen*, 1953, **73**, Apr. 9, 461–467). Oxygen refining during the production of high-alloy steels in the electric arc furnace has eased the alloy supply position, particularly of nickel. While large quantities of chromium and nickel alloy scrap have lain for years unused, it is now possible to use this as the sole raw material. An 80–85% recovery of chromium can now be ensured. High manganese scrap can be worked up, although with a lesser recovery. Other important alloying elements, such as tungsten, vanadium, nickel, molybdenum, copper, and cobalt can be retained by treating the melt with oxygen. A further advantage of oxygen refining is the reduction in the hydrogen and nitrogen contents of the steel.—J. P.

Timken Applies Inductive Stirring to 80-Ton Electric Furnaces. (*Iron Age*, 1952, **170**, Dec. 25, 82–84). Experience with an electro-magnetic inductive stirrer on a 20-ft. top-charged electric furnace is described. The stirring device is a water-cooled coil resembling a segment of the stator of a two-phase induction motor. The coils are in a container which is curved lengthwise only to fit the furnace bottom contour. Economic and metallurgical benefits are claimed.

Flicker Control in Arc Furnace Power Supply. R. F. Lawrence and R. L. Tremaine. (*Steel*, 1953, **132**, Feb. 23, 102–111; Mar. 2, 96–109). The authors consider voltage flicker arising from electric arc furnace operations, its causes, effects, limits, calculation, and control. The permissible cyclic variation in voltage recommended by several authorities is given and methods of determining voltage flicker in electric-furnace power systems are described. Corrective measures involve use of radial line or flicker bus bars, series capacitor or synchronous condenser with buffer reactor. The last is recommended for new installations.—D. L. C. P.

Chromium Pick-up by the Steel Bath in an Electric Arc Furnace Due to Spalling of Radex E Bricks in the Roof. (*Radex Rundschau*, 1950, No. 3, May, 160–161). A practical example is used to show that the effect of chrome magnesite bricks dropping into the steel bath is negligible. A graph is shown which permits direct reading of the degree of chromium pick-up.—E. C.

Arc Melting: New 20-ton Furnace at East Hecla Works. (*Iron Steel*, 1953, **26**, Mar., 91–92). **Hadfields' New 20-Ton Arc Furnace.** (*Brit. Steelmaker*, 1953, **19**, Mar., 132–135). **New 20-Ton Arc Furnace at Sheffield.** (*Iron Coal Trades Rev.*, 1953, **166**, Feb. 13, 355–357). **Hadfields' Furnace Installation.** (*Foundry Trade J.*, 1953, **94**, Feb. 12, 175–177). Details are given of some of the construction and design features of the 20-ton Birlec Lectromelt electric arc furnace recently put into service at Hadfields Ltd. The most notable features are the four-point suspension roof, top charging, and the B.T.H. Amplidyne electrode regulation gear.—G. F.

Principal Data for Basic Lined Electric Arc Furnaces. (*Radex Rundschau*, 1951, No. 1, Feb., 29–31). A brief survey of the main dimensions of basic-lined arc furnaces is made to permit assessment of the possibilities of increasing the weight of charge in consequence of reduced wall thickness with these linings.—E. C.

The Technique of Applying Magnesite. L. Hütter. (*Radex Rundschau*, 1950, No. 2, Mar., 91–124). The introduction of magnesite refractories into the ferrous and non-ferrous metal, cement, and chemical industries is surveyed, and advantages and principles of the design of basic-lined furnaces are discussed. Cooling and the performance of refractories are dealt with in some detail, and the standardization of brick sizes and furnace sections is described.—E. C.

The Lining of Electric Melting Furnaces in the Steel Industry. F. Harms. (*Radex Rundschau*, 1950, No. 4, Aug., 167–175). Lining techniques for electric arc, induction, graphite rod, and graphite electrode furnaces are described and discussed, and outstanding problems are considered.—E. C.

Low-Frequency Induction Furnaces in Steel Production. F. Sellner. (*Radex Rundschau*, 1950, No. 3, May, 153–159). The principles, construction, and development of low-frequency induction furnaces are described. Some steels produced in them are claimed to be equal or superior to crucible steels. Advantages and shortcomings are discussed and novel applications are mentioned, *e.g.*, using induction heating for automatic stirring in electric arc and open-hearth furnaces.—E. C.

Quality Control Aids in Steel Processing Control. W. R. Weaver. (Amer. Iron Steel Inst.: *Blast Furn. Steel Plant*, 1953, **41**, Feb., 198–202, 223; Mar., 307–310). The use of simple mathematical analysis (not a full statistical analysis) of a number of steelmaking operations is shown to lead to an improvement in the efficiency of the operations. Among the examples given is the control of the quality of ingots

for plate production. Each operation in the process is considered and a number of improvements were made.—B. G. B.

Autopour Makes Steel Pouring Easier, Safer, Better. T. H. Hoby. (*J. Met.*, 1952, **4**, Dec., 1282–1283). The author describes the mechanical 'Autopour' method of teeming steel, developed by the Republic Steel Corp. Hydraulic power is transmitted to the stopper-rod slide so that the movement of the stopper-rod can be controlled remotely by electric push-buttons. In addition to being a safer and easier method of teeming, it is claimed that the method has increased the number of sound ingots per cast.—G. F.

Continuous Casting Comes to Canada. H. W. Perry. (*Brit. Steelmaker*, 1953, **19**, Mar., 148–149). The continuous casting machine now being installed at the Welland (Ontario) works of Atlas Steels Ltd. will produce billets of $4\frac{1}{2} \times 4\frac{1}{2}$ in. and $5\frac{1}{2} \times 7\frac{1}{2}$ in. cross-section, and slabs of $5\frac{1}{2} \times 21\frac{1}{2}$ in. cross-section, at speeds up to 100 in./min. The operation of the machine is outlined, and a brief account is given of the development of continuous casting in the United States.—G. F.

Study of Exogenous Inclusions in Bottom-Poured Acid Steel. N. R. Krishnaswamy. (*Trans. Indian Inst. Met.*, 1951, **5**, 77–94). Typical inclusion studies are presented and show that, in general, silica enrichment at the inclusion surface occurs. An attempt is made to explain this enrichment based on: (*a*) A fundamental study by Körber and Oelsen which deals with the respective amounts of silicon and manganese in equilibrium in acid steel under various conditions of slag and temperature; and (*b*) the reactions of manganese oxide with the alumino-silicate phase of the refractory inclusions.—D. H.

PRODUCTION OF FERRO-ALLOYS

Electric Smelting at Bureau of Mines Seeks Utilization of Northwest Ores. R. T. C. Rasmussen. (*J. Met.*, 1952, **4**, Dec., 1273–1279). The electric smelting research facilities of the U.S. Bureau of Mines at Albany, Oregon, comprise batch-type arc melting furnaces, and a pilot plant smelter with two open-top pit-type furnaces for continuous smelting tests. The furnaces are described, and the problems and results of projects investigated are discussed. The projects include production of ferronickel from nickel silicates, direct smelting of manganese silicates to produce silicomanganese, reduction of Oregon iron ore, production of ferro-columbium-tantalum from tin slag, and production of ferro-chromium from off-grade chromite concentrates.—G. F.

Substitute Chromium Sources Reduce Production Costs of Stainless Steel. N. B. McFarlane. (*J. Met.*, 1952, **4**, Dec., 1284–1285). The author discusses some of the practices which have been adopted to reduce production costs of stainless steel by substituting other sources of chromium for low-carbon ferro-chromium. The substitute sources considered are low-carbon ferro-chrome-silicon, high-carbon ferro-chromium, and chrome ore, and examples are quoted to illustrate the possible savings in production costs.—G. F.

Domestic Chrome and Manganese Ores Can Be Upgraded and Utilized. H. A. Doerner. (*J. Met.*, 1953, **5**, Jan., 39–40). The shortage of metallurgical-grade chromium and manganese ores in America has led the U.S. Bureau of Mines to conduct extensive research work into methods of up-grading low grade ores by combinations of ore dressing and chemical treatment. The author outlines this work and also shows that the steel industry can efficiently utilize ferro-alloys produced from the crude concentrates of such ores without the need for the costly chemical beneficiation.—G. F.

Production of Spiegeleisen from Open-Hearth Slag in an Experimental Blast Furnace. R. C. Buehl and M. B. Royer. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1289–1294). The authors describe research work at the U.S. Bureau of Mines where a small experimental blast-furnace operating at blast temperatures up to about 1200° C. has been used to recover manganese from open-hearth slag and manganiferous iron ore. The process presents no unusual technical difficulties and a spiegeleisen with 14–23% Mn and up to 4% P is produced with a manganese recovery of about 60%. Typical operating results are presented.—G. F.

Production of High Manganese Slags by Selective Oxidation of Spiegeleisen. M. B. Royer and R. C. Buehl. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1295–1300). The authors describe small-scale tests on a 500-lb. basic converter vessel which indicate that preferential separation of manganese from high-phosphorus spiegeleisen (*see* preceding abstract) is feasible in basic converter operation. High manganese slags of consistently low phosphorus content can be produced by a cyclic operating process.—G. F.

The Manufacture of Ferro-Manganese and Alloy Steels in the Electric Furnace. J. Edwards. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 149–164). A brief history of the development of the electric furnace is given. There follows a detailed description of the 10-ton electric furnace at the Whyalla works of the Broken Hill Proprietary Co., Ltd.

FOUNDRY PRACTICE

Metallurgical Developments in Iron Foundries. A. J. D. Black. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Mar. 12, 291–298). The author reviews the ironfounding industry and then deals with recent progress towards the establishment of irons with clearly identified structures and properties, produced by various methods of metallurgical control. The effects of carbon, phosphorus and secondary elements are considered and the influence of alloying elements is briefly discussed.—L. E. W.

Research for the Foundry Industry. H. Morrogh, F. N. Lloyd, and W. A. Baker. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Feb. 19, 217–221; Feb. 26, 241–244). This article consists of three papers which broadly survey the research programmes at (1) the British Cast Iron Research Assoc., (2) the British Steel Founders' Assoc., and (3) the British Non-Ferrous Metals Research Assoc. At (1) a considerable part of the research is concerned with defects in iron castings; shell-moulding, sand control, and foundry techniques are also being studied; work is in progress on the effect of gases in cast irons. Direct-reading spectroscopy for the determination of carbon and phosphorus is being investigated. At (2) the properties of steel castings, non-destructive testing techniques, fettling and dressing of steel castings, and dust problems are amongst the current investigations. Problems being tackled at (3) include the solidification of alloys in the mould, the correlation of casting characteristics with alloy constitution, grain size and gas content, the effect of gas in cast copper-base alloys, and thermal gradients in solidifying castings.—L. E. W.

Foundrymen Can't Know too much About Practical Heat Transfer. W. S. Pellini. (*Amer. Foundryman*, 1953, **23**, Feb., 69–76; Mar., 59–69). The author reviews the past eight years' research on heat transfer. Initially, problems such as the authenticity of bleeding tests were studied using the electrical analogue. The results obtained are discussed. Some erroneous conclusions led to the 'end of freeze' curve being ignored. Later it was shown that the analogue correctly presented the course of solidification of the first casting and demonstrated the lack of reliability of bleeding tests. The subsequent analogue studies are discussed and compared with direct experiment, *i.e.*, thermal analysis data to indicate the extent to which the analogue data have been corroborated by research on the foundry floor. The analogue was directed to resolve the problem of the correct method of calculating relative solidification times; the Chvorinov relationships were found to be valid. The effect of metal and mould variables, chill size, dry and green sands were all investigated. (32 references).—L. E. W.

Casting Design in Relation to Production. J. H. Pearce and G. D. Whitehouse. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Feb. 12, 179–185). The features to eliminate in castings, such as hot tears, isolated masses, and corner stresses, are briefly discussed. The use of pads to improve feeding, and the introduction of ribs to increase the strength of a casting, are described. The more frequent use of 'cast/welded' units is recommended where satisfactory production as a one-piece unit is almost impossible. Various railway castings are discussed to show how modification in design has resulted in better castings, which in some cases have replaced fabrication.—L. E. W.

Contribution to Ideas on Productivity and Rationalization, and Rationalization Efforts in the German Foundry Industry. E. Piwowarsky. (*Giesserei*, 1953, **40**, Apr. 16, 203–210). The effect of mechanization and rationalization on the industry is shown by the increase in efficiency. The systematic arrangement of German foundry associations is described, together with their effect on rationalization. The Verein Deutscher Giessereifachleute, its organization, and the geographical location of its divisions are described. The

education of foreman melters and that of foundry engineers are discussed. Material testing and other factors influencing the productivity are enumerated.—R. J. W.

The Boudouard Equivalent Weight in the Cupola and the Effect of the Stack Height. W. v. Preen. (*Giesserei*, 1953, **40**, Mar. 19, 141–144). The theoretical basis for this work is first described. By neglecting the humidity of the air, the composition of the stack gases can be calculated using Boudouard's equivalent weights. The reaction temperature for an ideal adiabatic reduction is compared with that in a cupola. The effect of the height of the stack is discussed in the light of its effect on the heat content of the stack gases, and the preheating thereof.—R. J. W.

Investigations of Oxidation Losses Occurring in Cold and Hot Blast Cupolas. G. Clas and J. Schleissner. (*Giesserei*, 1953, **40**, Apr. 16, 190–193). Experiments are described using hot and cold blast in cupolas and the resultant losses and the relative amounts of pick-up are compared. Hot blast effects a considerable saving in the losses and extends the life of the plant. The system CaO–SiO_2–Al_2O_3 is also considered.—R. J. W.

Husqvarna's Hot-Blast Cupola. B. Tyberg. (*Gjuteriet*, 1953, **43**, Jan., 20–21). [In Swedish]. The general layout of this new Swedish plant is illustrated and briefly described. Normally not all the waste gases are required for preheating the blast, so the excess is directed to a waste-heat boiler for steam generation. Although the recuperator is equipped with suitable refractories, care must be taken to ensure that the temperature of the inflowing gas does not exceed 950–1000° C. This temperature is maintained by blowing cold air into the combustion chamber or recirculating cooled gases from the induced draught fan. The coke charged during hot-blast operation has decreased by approx. 37% and metal costs are lower, due to an increase in the proportion of scrap and home pig iron in the charge. Maintenance, cleaning, and depreciation charges are higher, however, but this does not outweigh the advantages obtained.—G. G. K.

New Cupola Emission Control Equipment Gives Faster Melting . . . Cleaner Air. (*Amer. Foundryman*, 1953, **23**, Feb., 41–43). The new hot blast and stack gas cleaning system at the National Malleable and Steel Castings Co. is described. The new equipment includes a gas-fired after-burner at the charging door. The stack is tightly capped with a hinged cover plate which acts as an explosion door. The hot gases are drawn off 11 ft. above the charging door to the heat exchanger in which they expand and change their direction of flow to the exhaust duct. The waste gases are drawn from the heat exchanger through a washer and then a cyclone collector before being finally exhausted through a 120-ft. stack.—L. E. W.

Height-of-Charge Indicator for Cupolas. R. I. Taylor. (*Foundry Trade J.*, 1953, **94**, Feb. 19, 216). The author describes a height-of-charge indicator for permanent attachment to cupolas. The indicator works in conjunction with the 'cupola pyrometer' introduced by the author and consists essentially of a lamp actuated by a thermostat. The operating sequence is detailed.—L. E. W.

Basic Cupola Operation—Dephosphorization of Iron. J. E. Bolt. (*Amer. Foundryman*, 1953, **23**, Mar., 50–53). The author reports on an investigation on the dephosphorization of iron in basic cupola operation. Details of the cupola (lining, slag, and metal levels) used in the experiments are given and the experimental procedure is described. Successful dephosphorization in basic cupola operation can be accomplished on a production basis by using insulation between the shell and basic brick lining, and sufficient coke to maintain slag and metal fluidity.—L. E. W.

Calcium Carbide Injection Is New Tool in Gray Iron Metallurgy. H. E. Henderson and P. M. Hulme. (*Foundry*, 1953, **81**, Apr., 86–91, 241–247). The authors describe how calcium carbide injection into molten iron can be employed for: Desulphurizing to conventional ranges; desulphurizing to extremely low levels which provide minimum chilling tendency and permit use of more economical alloy additions; desulphurizing as a basis for spheroidal graphite cast iron; to improve and spheroidize iron of low tensile strength. Details are given of the carbide injection tube and the flux feeder carbide system. The compositions and physical properties of various irons before and after treatment are included.—L. E. W.

Studies of Gases Evolved on Solidification of Molten Cast Iron (III). M. Otsuka. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 26–30). [In English]. It has been thought that wasters increased in the rainy season, due to increase in hydrogen content of cast iron, but systematic observations over a year disproved this. In laboratory trials, wet air, steam and hydrogen were blown on to molten iron in various conditions. In most cases hydrogen or CH_4 were not found in the evolved gases. Blow-hole formation and wasters can therefore not be ascribed to a humid atmosphere.

Cast Iron Pipes and Sand-Stowing Pipes. A. E. Crawley and D. K. Coutts. (*Trans. Min. Geol. Met. Inst. India*, 1950, **46**, Oct., 159–169). The production of cast-iron pipes is discussed. The use of cast-iron pipes for the transfer of a suspension of sand in water (sand-stowing) is considered. The joining of the pipes is also considered.—B. G. B.

Nodular Iron Casting Practice. H. Gries. (*Giesserei*, 1953, **40**, Feb. 19, 93–103). An introduction is given to nodular iron casting in the German foundry industry and the essentials of their manufacture and composition are described. During manufacture, the aim is to have a low silicon content (0·8 to 1·5%), and to anneal in such a manner that the carbide is decomposed and secondary spherolithic formation follows. By suitable annealing and cooling conditions, a greater percentage of high quality material can be produced. The textures of the raw and final material, and their effect on the strength and on the graphitic formation are illustrated. Casting and gating techniques are described.—R. J. W.

Australian Experiments with Nodular Cast Iron. R. B. Whitelaw and E. R. A. Pohl. (*Foundry Trade J.*, 1952, **93**, Dec. 25, 737–739). In the first part, R. B. Whitelaw mentions the superiority of electric-melted iron with low sulphur, for treatment. Crushed magnesium–nickel or magnesium–copper alloys were placed in the ladle before filling it with steel. Experimental casts with varying base irons showed encouraging improvements in mechanical properties. In the second part, E. R. A. Pohl deals with the results of making nodular cast iron, *i.e.*, a more fluid slag, good metal fluidity despite the increased chilling, and unusual shrinkage. Nodular iron has a lower damping capacity than grey iron, but better wear resistance, fatigue strength, and machinability.—E. T. L.

Some Experiments on the Structure Diagram and the Annealing of Spheroidal Graphite Iron. N. Tsutsumi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 6–10). [In English]. The structures of 70 compositions of iron (C 2·4–4·5%, Si 0–4·6%) with and without magnesium additions, were investigated in the as-cast condition, and after annealing to produce graphitization and pearlite decomposition. Results are presented as the structure diagram, and graphs of size and number of nodules as cast, graphitizing speeds of primary and pearlitic cementite, and growth of spheroidal graphite. Graphitizing speed largely depends on silicon content. Conditions for manufacture of malleable iron with high strength and ductility are described.—K. E. J.

Spheroidal Graphite Cast Iron. (Report 1). T. Kusakawa, R. Kanda, and M. Kanie. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 25–32). [In English]. Experiments were made to explore the main factors of spheroidal graphite formation (*viz.*, amount of magnesium addition and section size). Very small magnesium additions produce white iron when section size is < 3 mm., but above 5 mm. 0·65% magnesium produces spheroidal graphite iron. The stabilizing effect of magnesium somewhat retards graphite growth. The crystal form of the graphite, decomposition of pearlite and cementite, and ferrite formation are also discussed.

Spheroidal Graphite Cast Iron (Report II). T. Kusakawa. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 11–14). [In English]. Spheroidal graphite cast iron can be produced from ordinary cast iron by adding $> 5\%$ Ca_2Si, and from nickel cast iron by small additions. Ductile irons are readily produced subsequently. The disadvantages are the quantities of addition elements and high melting temperatures.

A Theory of Globular Graphite Formation in Cast Iron. I. Iitaka. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 1–4). [In English]. Various mineralogical forms of graphite are described, and identified with graphites in cast iron. The growing of lump, flake, and globular forms from small nodular nuclei is discussed. A hypothesis for globular graphite formation is advanced, based on adsorption of magnesium and cerium, with consequent change in surface tension. (12 references).—K. E. J.

Theories of Graphite Formation in Nodular Cast Irons. M. N. Parthasarathi, B. S. Srikantiah, and B. R. Nijhawan.

(*Trans. Indian Inst. Met.*, 1951, **5**, 227–243). Available literature on graphite formation in nodular iron is reviewed. The theories advanced to explain nodular graphite formation in irons treated with magnesium and cerium are presented. The theories are discussed in detail and some of the outstanding factors that have to be clarified are listed.—D. H.

Progress of Spheroidal-Graphite Iron. W. W. Braidwood. (Centro Fonderia: *Foundry Trade J.*, 1953, **94**, Feb. 26, 231–236). The author surveys of the production of spheroidal graphite iron, its properties and applications. (14 references).

Safety Practices in the Production of Ductile Iron. R. E. Savage. (*Amer. Foundrymen*, 1953, **23**, Apr., 145–149). The author discusses various health and safety hazards in the production of ductile iron and recommends precautions to be taken. (13 references).—L. E. W.

Mechanised Foundry for Small Blackheart Malleable Castings. J. Roxburgh. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Mar. 19, 321–331). The author describes the new mechanized plant at Ley's Malleable Castings Company, Ltd., for producing small castings, with emphasis on significant differences as compared with grey ironfounding. The output of the plant is approximately 50 tons per week.

Studies of Gases Evolved on Solidification of Molten Cast Iron (IV). I. Iitaka and M. Otsuka. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 15–16). [In English]. Gas evolution is less with charcoal pig than with cupola cast iron. When magnesium only is added, gas volume shows a minimum. Nodular graphitization treatment produces increased evolution, of the same order for the two irons. Silicon addition increases evolution. Gas composition is also influenced by graphitization.—K. E. J.

Interaction of Hydrogen with White Cast Iron. P. C. Ghosh and B. Chatterjee. (*Trans. Indian Inst. Met.*, 1951, **5**, 215–225). The withdrawal or otherwise of carbon, sulphur, and phosphorus from a sample of white cast iron (C 3·08%, Si 0·88%, Mn 0·216%, P 0·21%, and S 0·10%) at 1000° C. under flowing hydrogen containing 1·2% moisture was studied. The mechanism of the interaction between hydrogen and alloys of iron, carbon, sulphur, and phosphorus is discussed. The theoretical aspects of the subject are dealt with under the headings decarburization, dephosphorization and desulphurization.—D. H.

High Quality Steel Casting. F. Harms. (*Radex Rundschau*, 1949, No. 6, Oct., 220–237; 1950, No. 1, Jan., 62–74). An historical survey and description of the development of steel casting are followed by an account of the evolution of cast alloy steels for special purposes. Correctly produced steel castings are claimed to be in no way inferior to forged or rolled steels. Methods of production are described and discussed, including mould making, melting, heat-treatment, and material testing. Centrifugal casting is also dealt with.

Effect of Liquid Metal Temperatures on Grain Size of High Manganese Steel. S. L. Gertsman. (*Amer. Foundryman*, 1953, **23**, Feb., 48). This brief report throws light on the controversy concerning the influence of liquid metal temperature on Hadfields manganese steel.—L. E. W.

The Determination of the Structural Formation of Compressed Sand Moulds. W. Reitmeister. (*Giesserei*, 1953, **40**, Mar. 19, 144–149). The structural formation of compressed sandy material when correlated with the corresponding aeration curve, provides an insight into the nature of sand, and simultaneously shows the volumetric distribution of the sand constituents in the compressed form. Testing methods are critically examined. The calculation and presentation of the formation of the texture yield a relationship between the structure form and the density.—R. J. W.

Effect of Sand Flowability on Casting Surface Finish. H. H. Fairfield and J. McConachie. (*Amer. Foundryman*, 1953, **23**, Apr., 127–132). The authors report on experiments to measure flowability of moulding and core sands and to relate flowability values to surface finish. The experimental procedure and equipment used are described. The conclusions are: (1) Casting finish depends in part on the ability of sand to flow under ramming. (2) The Kennedy flowability test was shown to be related to casting finish on eight different sand mixtures. (3) The A.F.S. Flowability Committee test procedure correlated with the Kennedy flowability test procedure on four different sand mixtures.—L. E. W.

How Foundrymen Can Get the Most from Naturally Bonded Sands. C. A. Sanders. (*Amer. Foundryman*, 1953, **23**, Mar., 37–40). The author discusses the advantages and disadvantages of natural moulding sands and their proper application, with reference to the rules for avoiding clay balls, the control of moisture, the need for addition of new sand, and causes of deformation.—L. E. W.

Zircon and Its Foundry Applications. W. M. Peterson. (*Foundry*, 1953, **81**, Apr., 92–95). The author describes how to make the best use of the properties of zircon as a moulding material. These properties are: High refractoriness, conductivity, and density; and low expansion and resistance to wetting by molten metal. Zircon mixtures for various applications are given and discussed.—L. E. W.

Casting in Cement Bonded Sand. J. B. McIntyre. (*Foundry*, 1952, **80**, Dec., 90–91, 269). Silica sand may be bonded with Portland cement. Ramming is unusually easy, but the mixture has little green bond, and sets within 5 hr. Storage for up to two days permits hardening. No flasks are needed, which is helpful with large castings. The main use of cement-bonded sand is in making manganese-bronze or aluminium–bronze marine propellers.—E. T. L.

Hot Strength at Falling Temperatures—Does It Influence Hot Tear Formation? D. C. Williams. (*Amer. Foundryman*, 1952, **22**, Nov., 47–50). Experimental data show that the hot compressive strength of a particular sand mixture is different when heating and when cooling. The author relates this and a consideration of glass formation to the problem of hot tears, suggesting that glass formation may be prevented by good heat dissipation through the sand.—E. T. L.

On Molding Sand Binders. T. Makiguchi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 38–41). [In English]. The relationships between baking strength and high temperature strength, and between grain stability and casting surface conditions, are examined for several binders. With organic binders, the zone of maximum binding power is 200–300° C., with clayey materials, 500–600° C. The most suitable materials have characteristics of strength by coagulation and sintering in the appropriate temperature range, and good stability.—K. E. J.

Studies on Molding Sand Binders. T. Makiguchi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 37–42). [In English]. The influence of *p*H on the properties of several clay-type binders is reported. Binding strength and sedimentation velocity are very sensitive to small changes in electrolyte amount, their variations being in the same direction. Absorption or chemical reactions occur among the colloidal particles, according to electrolyte concentration.

Synthetic Resins as Sand Bonds. P. G. Pentz. (Inst. Brit. Foundrymen: *Foundry Trade J.*, 1952, **93**, Dec. 25, 729–733). The author deals with the characteristics of foundry resins and their performance, with emphasis on practical difficulties, and promising developments. The two types available are urea- and phenol-formaldehyde resins, both being complete substitutes for linseed oil. A graph shows how there is an optimum water content of the sand for maximum green strength.—E. T. L.

Room and High Temperature Properties of Synthetically Bonded Molding Sand. Mary T. Zemantowsky. (*Amer. Foundryman*, 1953, **23**, Feb., 57–61). This paper presents data on sintering temperatures, hot compressive strengths, and green properties of washed silica sand mixtures containing specific additions of western bentonite, at different moisture contents. No direct relationships were observed between the A sintering point, the bentonite-water ratio, and other properties of the sand mixtures studied. Effect of moisture variations were usually less pronounced than variations in bentonite content. (35 references).—L. E. W.

Sand Reclamation at Lynchburg Foundry. L. E. Wile. (*Iron Worker: Foundry Trade J.*, 1953, **94**, Feb. 19, 207–215). The author describes arrangements at the Lynchburg Foundry for the conservation of moulding sands, diminution of waste, elimination of delays in delivery, in conjunction with production of better sand properties and reduced cleaning of castings. A schematic layout of the sand reclamation unit is included.—L. E. W.

Ramming Cores with Reclaimed Sand. H. W. Haynes. (*Foundry Trade J.*, 1953, **94**, Mar. 26, 347–350). The author gives an account of impeller ramming used in conjunction with sand reclaimed from the Hydroblast plant. The operational sequence is described, and details given of the equipment employed at the National Gas and Oil Engine Co., Ltd.

An Aid to the Determination of the Material Nature of Pulverized Core Binders. F. Roll. (*Giesserei*, 1953, **40**, Mar. 5, 127–128). A hot-stage microscope is described and illustrated; it has a useful magnification of about 300. It has been used to observe the behaviour on heating of constituents of pulverized core binders.—R. J. W.

Machining Methods for Master Patterns. (*Foundry Trade J.*, 1953, **94**, Apr. 9, 413–414). The author describes briefly, with illustrations, machining methods for making patterns.

REFA-Work in Pattern Construction. F. Lamm. (*Giesserei*, 1953, **40**, Apr. 16, 193–203). Systematic work and time studies are first considered from the following points of view: Work flow, work time, work value, and material studies. The recovery time and the overall efficiency are dealt with. The method of calculating the most economic process is outlined with an example. Price fixing and supply are considered and illustrated by more examples.—R. J. W.

Note on the Manufacture of Precision Pattern Plates. B. Faure. (*Fonderie*, 1952, **83**, Dec., 3227–3232: *Foundry Trade J.*, 1952, **93**, Dec. 25, 723–727). A detailed description is given of a method employed to make pattern plates for the production of thin castings of relatively large surface area. Precision is necessary to ensure an even thickness in the castings produced from the pattern.—J. McK.

The Principles of Risering. C. F. Walton. (*Foundry*, 1953, **81**, Feb., 100–107, 244–245). The author discusses the reasons for the application of a riser to a casting. Metal solidification and cooling gradients are considered with illustrations of the various possible shrinkage effects. The broad applications of risers to different types of casting are described and the merits of side, top, and Williams risers indicated.—L. E. W.

Washburn Cores Disinterred—Pros and Cons of Necked Down Risers. J. B. Caine. (*Amer. Foundryman*, 1953, **23**, Feb., 51–54). The author reviews the advantages and limitations of 'necked-down' risers. Shrinkage due to long feed distance and segregation are the only legitimate limitations known to the author. Other objections are discussed and attributed to the inefficient application of other basic foundry principles.—L. E. W.

Gating Technique in the Iron Foundry. W. Kumpmann. (*Giesserei*, 1953, **40**, Feb. 19, 110–112). Examples of suitable gates and risers to be used on multiple castings for double helical gears, gear wheels, cylinders, and rods are described and illustrated. The two factors that play the most important part in casting are the temperature of the iron and the wall thickness of the casting. These are correlated with the other important factor, the speed of casting.—R. J. W.

On the Flow-Dynamic of Molten Metals (Part II). K. Yokota. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 52–55). [In English]. The flow of molten metals in runners was simulated by studies of mercury. Results are presented for varying roughness of the channel, and the influence of roughness, channel inclination, and head of weir on the metal flow pattern.—K. E. J.

Jolt Rockover Molding Machines. K. M. Smith. (*Amer. Foundryman*, 1952, **22**, Nov., 36–38). Eleven machines are illustrated and briefly described.—E. T. L.

How to Standardise and Set up Multiple Molding in a Malleable Shop. J. G. Kropka. (*Amer. Foundryman*, 1953, **23**, Mar., 44–49). The author surveys the basic equipment and methods employed for multiple moulding at the Malleable Division of the Chain Belt Co., Milwaukee. The need of continuity of operation is stressed. Methods of sand handling, moulding, pouring and shake-out operations are presented. The need for standardizing flasks, machines, and moulding procedure to meet specifications and production requirements is emphasized.—L. E. W.

Relation between Baking Time and Thickness of a Core. M. Decrop. (*Fonderie*, 1953, Jan., 3281–3285). Experiments are described to determine the baking times (defined as the time for the centre of the core to reach the ambient temperature of the oven) required for cores of the same composition but different dimensions. For cubic cores baking time was found to be proportional to the square of the cube side and for other shapes it was established that baking time varied as the square of the ratio of core volume to core surface.—J. McK.

Monorail Conveyor System Reduces Blast-Cleaning Costs. W. I. Gladfelter. (*Foundry*, 1952, **80**, Dec., 104–105, 263–265). Car cylinder blocks, hanging from a monorail, turn slowly while passing through a blast room. The abrasive is thrown from wheels with compressed air. The arrangement conserves space and is a good method of cleaning castings.

High-Speed Molding Is Done Automatically. W. G. Gude. (*Foundry*, 1953, **81**, Apr., 98–101). The author describes the high-speed production of uniformly rammed, medium-sized moulds, as achieved by the Symington-Gould Corp. with an automatic moulding unit recently installed at its steel foundry. The principal feature of the installation is an indexing moulding machine which incorporates two tables, the drag pattern being mounted on one and the cope pattern on the other.—L. E. W.

On Camlachie Cramp (Report 1)—Especially on Chaplets. T. Muraki. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 50–53). [In English]. The operation of the Camlachie cramp in casting processes depends on thermal or chemical conditions favouring welding between solid and fused metal. The use of steel chaplets in casting grey iron has been investigated for cases where oxide films are and are not present.

Studies on Camlachie Cramp. T. Muraki. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 43–45). [In English]. Chemical factors affecting the welding of grey cast iron to mild steel chaplet stems were investigated. Stems plated with silver, brass, copper, and nickel showed good weldability, but not those plated with chromium: adsorbed hydrogen tends to form blow holes. Powdered metal facings are not recommended for promotion of welding, though results with water-glass as a binder are better than those with oil.—K. E. J.

Shell-Moulding Machinery. (*Foundry Trade J.*, 1953, **94**, Mar. 26, 351–352). Details are given of two of the Sutter range of machines at present being manufactured by Foundry Equipment, Ltd., of Linslade Works, Leighton Buzzard. One will produce shells up to 30 by 20 in. and the other up to 41 by 26 in.—L. E. W.

Mystery of Shell Molding Patterns Explained. R. Olson. (*Amer. Foundryman*, 1953, **23**, Apr., 135–139). Shell moulding patterns are broadly discussed and the type of equipment employed is indicated.—L. E. W.

New Method Simplifies Shell Mold Assembly. R. Herold. (*Foundry*, 1952, **80**, Dec., 142, 144). The technique described is applicable to all patterns having their parting lines in one plane. The cope with male bosses pointing downwards is dipped $\frac{1}{8}$ in. into glue, and then placed on the waiting drag. The bond is then adequate for small castings. Greater locating accuracy and speed are achieved by this procedure when gluing interlocking bosses and recesses.—E. T. L.

The "C" Process of Casting. M. C. Dixon and R. S. Bushnell. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Mar. 26, 355–364). The authors present a general account of the Cröning, "C" or shell process as practised in England. The process is based on using a mixture of synthetic resin and sand to form a thin shell mould. The resins may be of the phenolic, cresylic or urea types, and Chelford (processed, fine) and Redhill (grade H) are two sands which give good results. The required properties of the resin and sand are discussed.—L. E. W.

Where Shell Mold Castings Stand Today. K. Rose. (*Mat. Methods*, 1953, **37**, Jan., 73–77). The Cröning or shell moulding process for precision casting is described, and specific cost figures and an appraisal of the properties of shell-moulded castings are given.—P. M. C.

Shell Moulding with Urea-Formaldehyde Resins. (*Machinery*, 1953, **82**, Mar. 20, 526–532). A range of resins based on urea-formaldehyde is supplied by British Industrial Plastics, Ltd. Notes on their use are given and the shell moulding process is described.—E. C. S.

Producing High-Quality Iron Castings in Shell Moulds—Methods Employed by Macmillan Foundries Ltd., Watford. (*Machinery*, 1953, **82**, Mar. 6, 419–426). Since shell moulding was adopted by Macmillan Foundries Ltd., more than 14,000 castings have been poured. All these were of high-grade cylinder iron which usually contains hematite, refined iron, steel, cylinder block scrap, and refining agents, and were low in phosphorus.—E. C. S.

Shell Moulding. L. Villner. (*Gjuteriet*, 1953, **43**, Jan., 1–12). [In Swedish]. On the basis of observations made abroad, especially in the U.S.A., and data in the literature, the author describes the technique of shell moulding. Sections deal with sand, resin, parting agents, patterns, machines for shell and core production, methods of making the shell and

assembling the mould. Advantages and disadvantages of the process are discussed. Details are given of the possible financial outlay involved.—G. G. K.

Design and Production of Shell Mold Patterns Improved. (*Iron Age*, 1952, **170**, Dec. 11, 172–174). The problems involved in the design of patterns for shell-moulding because of the heating and cooling cycles are discussed. Cast iron is favoured at the moment but there are possibilities of using aluminium. Pattern plates as large as 16 × 24 in. have been made where dimensions are held to within 0·002 in.; distortion has been eliminated by increasing the pattern section and stress-relieving before final machining.—A. M. F.

Mass-Production Casting by Investment Moulding. (*Foundry Trade J.*, 1953, **94**, Mar. 19, 333–336). This is a survey of the history and present-day status of the process for producing extremely accurate castings using expendable patterns. Each stage in investment moulding is described and the merits of the process and its potentialities are dealt with.—L. E. W.

How Precise Is Investment Casting? P. R. Kalischer. (*Precision Met. Mold.*, 1952, **10**, Oct., 36–37). The author gives a short note on the dimensional tolerances and reproducibility to be expected from precision casting.—D. H.

Fatigue of Moulds Used in Pressure Die Casting. R. Grunberg. (*Mét. Constr. Mécan.*, 1952, **84**, Dec., 923–927). Five causes of failure of moulds during service are considered: (1) The pressure exerted during the casting process; (2) thermal shock; (3) the chemical action of the alloy on the mould; (4) erosion of the mould by the moving liquid alloy; and (5) the contraction after heating.—B. G. B.

Use of Investment Castings in Aircraft Structural Parts.—Part I. A. C. Williams and J. H. Massa. (*Precision Met. Mold.*, 1952, **10**, Nov., 34–36; Dec., 29–31). The authors discuss the general subject of investment castings, dealing with such factors as tolerances and mechanical properties, and describe the stages in the development of a latch housing and a bell crank casting.—D. H.

Basic Considerations in Planning Mechanization of a Small Foundry. W. A. Morley. (*Amer. Foundryman*, 1952, **22**, Nov., 53–58). The sequence proposed is: (1) Determine the reason for mechanization; (2) review present facilities, people, and sales; (3) draw up a plan; (4) decide on the action necessary; and (5) follow up results. The author considers each of these steps in turn.—E. T. L.

Mechanics of Foundry Mechanization and Improved Methods. R. J. Anderson. (*Amer. Foundryman*, 1953, **23**, Apr., 114–120). Mechanization techniques and improved methods in the foundry for reducing costs and improving quality are discussed. Neither step alone will develop maximum savings; improved work methods are especially desirable in the smaller shop and mechanization calls for good preventive maintenance.—L. E. W.

The Control of Centrifugal Compressors and the Cost of Compressed Air. F. Imberger. (*Giesserei*, 1953, **40**, Mar. 5, 117–127). The principles of centrifugal compressors, often used to supply foundries with compressed air, are elucidated and the five useful methods of control described and compared. The economics of compressed air are discussed from the point of view of running costs as well as initial outlay. Throttle regulation, due to its simplicity and reliability, is the most useful mode of control. The distribution of the load for mean load and peak load compressors is described.

Longer Life Cast into Modern Slag Ladle. (*Foundry*, 1952, **80**, Dec., 108–111, 174, 177). This is a description of the design and casting of the improved Johnston ladle made by Mackintosh-Hemphill Co., Midland, Pa. The crane hook has been improved, and now the ladle is suspended from lugs instead of standing on feet. Also the inside bottom is coated with copper. The rim can expand, and the base is air-cooled.

New Roll Foundry Completed in Great Britain. V. Delport. (*Foundry*, 1953, **81**, Feb., 108–111, 246–247). A brief description is given of the new roll foundry at Crewe. At present, the foundry produces about 175 tons of finished castings per week and melts 250 tons of metal in four top-charged air furnaces, two of 15 tons and two of 25 tons. Production will be about doubled when two new 30-ton air furnaces are in operation.—L. E. W.

A Modern Stove Foundry. A. R. Parkes. (*Foundry Trade J.*, 1953, **94**, Apr. 2, 377–383). The author describes the foundry of Aga Heat, Ltd., at Ketley, Shropshire, which is equipped specifically for the production of stove-grate castings. The layout is surveyed and an account given of the working methods from the metal melting to the knock-out station and casting removal.—L. E. W.

Elements in the Cause and Cure of Residual Stresses in Cast Iron. L. A. Aldinger. (*Amer. Foundryman*, 1953, **23**, Mar., 77–78). The author discusses the effects of differential solidification, blast cleaning, and restricting influence of the mould in setting up residual stresses in a casting. Stress relieving is considered and illustrated with photomicrographs of two cast irons.—L. E. W.

Surface Defects on Steel Castings—Modes of Occurrence and Means of Prevention. D. V. Atterton. (*Iron Steel*, 1953, **26**, Mar., 93–97). The author discusses the modes of occurrence of surface defects in steel castings, dealing with: Dirt spots and inclusions; cold laps; misruns; blowholes, blows and pinholes; metal penetration and burnt-on sand; and scabs, buckles, and drops. General suggestions for the reduction of surface defects are put forward, with emphasis on the properties of the sand-mix used.—G. F.

Relation between Melting Conditions and Casting Defects in Iron Casting (Report II). N. Kayama. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 3–5). [In English]. Laboratory and full-scale investigations show that shrinkage cavities are related to the SiO_2 present, although its form of occurrence is not known precisely. Cast iron should be melted at high temperatures, when the SiO_2 is reduced.—K. E. J.

Quality Control in the Small Foundry. W. J. Sommer. (*Foundry*, 1952, **80**, Dec., 92–95, 265–268). The causes of wasters should be noted and analysed, and records kept of sand tests, metal analyses, and pouring temperatures. The relevant sand tests are for moisture, permeability, and green compression strength. Chill tests are recommended. The sequence of inspections, tests, and records is traced from the receipt of the customer's order.—E. T. L.

Quality Supervision in the Small Jobbing Foundry. E. Fry. (*Foundry*, 1953, **81**, Feb., 97, 248–250). The author discusses briefly the danger of overlooking the human factor in the development of mechanization and new processes in the small jobbing foundry.—L. E. W.

Tolerances and Specifications for Grey-Iron Castings. C. O. Burgess. (Amer. Soc. Mech. Eng.: *Foundry Trade J.*, 1953, **94**, Feb. 19, 203–205). As-cast tolerances are discussed and some pattern shrinkage allowances for grey iron are tabulated against pattern dimensions. Alteration of the casting from static to centrifugal methods does not normally alter the usual tolerances, and unusually close tolerances are claimed for shell-moulding. Finish or machine tolerances and jig locations are also dealt with.—L. E. W.

Evolving Gases on Solidification of Molten Cast Iron (Report 2). M. Nakano. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 46–49). [In English]. The influence of melting methods on composition of evolved gases was studied using Penhsihu pig iron in a cryptol furnace. Gas composition depends on the value of (% C + % Si) in the iron. The CO was high with high-temperature melting. A relationship between iron composition and the ratio $CO/(CO + CO_2)$ is traced. Hydrogen evolution from cast iron melted in a high-frequency furnace is approx. 2–3%.—K. E. J.

Relation between Melting Conditions and Casting Defects in Iron Castings. (Report 1). N. Kayama. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 15–19). [In English]. Melting conditions were investigated on a small model cupola. Melting temperature has a great effect on the formation of the shrinkage cavity, and should be 1450° C. or above. The volume of shrinkage cavity is reduced by reduction in the product (blast volume × melting time per unit weight of raw material), since oxidation is obviated.—K. E. J.

On Metal Penetration in Casting. (Report 2). J. Kashima. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 11–14). [In English]. With special steel castings, experimental work shows that penetration can occur if surface oxidation is present, or if there is no selective oxidation of addition elements (as with copper castings); it is influenced by any sintering reaction between metallic oxides and sand grains, and by the casting temperature. Results are given from investigations of several types of chromium and manganese steel castings.—K. E. J.

French Foundry Center Completes Extensive Laboratories. V. Delport. (*Foundry*, 1952, **80**, Dec., 106, 107, 263). The buildings, opened in June, 1952, cover 43,000 sq. ft. and provide for studies in chemistry, physics, and on the thermal properties of foundry sands. A fifth department conducts melting

experiments. There is a 20-in. cupola, and another of 10-in. in dia. Vitreous enamelling, and electrolytic coatings are dealt with here, along with tests on domestic heating appliances. Consultant services are available. Finance is provided by a levy of 0·4% of the value of industrial castings.—E. T. L.

Foundry Dust Control: Research on Grinding Machine Exhaust Systems. (*Iron Steel*, 1953, **26**, Mar., 80). Research work by the British Steel Founders' Association has led to outstanding improvements in dust suppression on stand or pedestal grinding machines, with wheels of high or medium peripheral velocity. Modifications to the exhaust systems, which are described, can be easily fitted to both existing and new machines.—G. F.

A.F.S. Safety, Hygene, and Air Pollution Program. J. R. Allan. (*Trans. Amer. Found. Soc.*, 1952, **60**, 279–281).

Health and Safety in Foundries. (*Foundry Trade J.*, 1953, **94**, Feb. 5, 155–156). This article consists of abstracts taken (with some paraphrasing for clarity) from special regulations applying to iron and steel foundries. These draft regulations, which are called the Iron and Steel Foundries Regulations, 1953, contain requirements concerning the safety, health, and welfare of foundry workers.—L. E. W.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Centralised Heat-Treatment Equipment for Mining Gear. C. P. MacCarthy. (South Wales Inst. Engineers: *Colliery Guardian*, 1953, **186**, Mar. 19, 343–346). Periodic heat-treatment to avoid surface embrittlement of wrought iron parts, and to remove internal stresses in mild steel, is essential for maintaining the safety of cage suspension equipment. Three types of heat-treatment furnace are described and their relative merits are discussed. Testing of components is also mentioned.—T. E. D.

Continuous Heat-Treatment Process Produces High Strength Oil Well Casing. F. H. Bremmer and F. J. Zehnder. (*Iron Steel Eng.*, 1953, **30**, Jan., 55–62). This paper describes a new continuous quenching and tempering line producing high strength oil well casing from plain carbon steel at the Ambridge plant of the National Supply Co. Details are given of the sequel of operations, manning, handling equipment, furnaces, quenching equipment, maintenance routine, and products manufactured.—M. D. J. B.

Practical Metallurgy "Down-Under." A. S. Reardon. (*Metal Progress*, 1953, **63**, Jan., 99–102). The development of heat-treatment facilities in Australia is discussed.—B. G. B.

Hardening Gray Cast Iron with Minimum Distortion. A. A. Armstrong. (*Amer. Foundryman*, 1953, **23**, Apr., 142–144). The advantages and limitations of oil quenching and tempering, martempering and austempering are discussed. Control of distortion in hardened cylinder liners is discussed with reference to the TTT curve. For good wear characteristics, a hardened grey cast iron with random graphite in a matrix of tempered martensite or bainite is recommended.—L. E. W.

Gas Carburizing Plant. (*Overseas Eng.*, 1953, **26**, Apr., 316–317). One of the methods of producing gears is in accordance with the Maag principle, which gives a very high wear resistance. The article describes the production of case-hardened marine gears with particular reference to the re-equipping of the hardening department.—J. C. B.

Development, Principles and Applications of Interrupted Quench Hardening. R. F. Harvey. (*J. Franklin Inst.*, 1953, **255**, Feb., 93–99). The development of the interrupted quench hardening (or martempering) technique is reviewed. This is widely used for the hardening of steel parts and it should be a good process for hardening brazed assemblies. Shot-peening the metal while hot and still austenitic, after removal from the low temperature bath (above or at the M_s point), results in a higher compressive stress at the surface than can be imparted by the conventional cold-peening method.

Flame-Hardening and Tempering of Wire. A. R. Wilson. (Inst. Gas Engineers: *Indust. Gas*, 1952, **16**, Dec., 76–78). A general description is given of the flame-hardening and tempering of card wire used in the textile industry, and the theory of the processes is explained. Temperature measurement of hot moving wire is discussed, and details are given of investigations carried out on the development and application of burners.—D. H.

Salt versus Atmosphere Annealing. E. S. Tyler. (*Wire and Wire Prod*, 1953, **28**, Feb., 156–157, 219–222). The author bases his views on his experience with annealing of low and medium carbon wire in the range 0·5–0·007 in. in dia., at the Atlantic Wire Co., Branford, Conn. Salt annealing equipment has the advantages of low initial and maintenance costs, better uniformity of product, and flexibility of output. The controlled atmosphere equipment can cope with a much wider range of sizes, grades of material, and finishes.—J. G. W.

Solubility of Carbon. S. J. Rosenberg and C. R. Irish. (*Wire and Wire Prod.*, 1953, **28**, Mar., 266, 301–302). Results of an investigation into the solubility of carbon in chromium–nickel austenitic stainless steel are reported. The data are applied in recommendations for annealing these steels. It is found impracticable to produce alloys with a sufficiently low carbon content for the suppression of carbide precipitation under all conditions of service.—J. G. W.

Many Common Metals Successfully Treated in Steam Atmospheres. F. L. Spangler. (*Mat. Methods*, 1953, **37**, Jan., 85, 86). Scale-free tempering, annealing, and stress-relieving of small components can be effectively carried out at temperatures up to 1150° F. in furnaces through which steam is passed. In many applications the thin blue-black oxide film so formed is a tough, durable, low cost, finish. It is also claimed that superior wear resistance, better machinability, and greater resistance to corrosion are obtained for steel.

FORGING, STAMPING, DRAWING, AND PRESSING

Free Forging With and Without Traverse with Hydraulic or Steam Forging Presses of 1000 to 15,000 Tons. (*Hutnik*, (Prague), 1953, **3**, 1, 18–20). [In Czech]. The two methods of forging as practised at the major Czechoslovak steelworks are discussed and the advantages and disadvantages of each are listed. Proposals are made for exploiting the advantages of both methods in presses of new design.—P. F.

Improved Manufacture of Large Alloy Steel Forgings. H. H. Burton. (*Metal Progress*, 1953, **63**, Jan., 125–129). The author discusses the recent developments in making large alloy steel forgings, in particular of 3%-Cr–Mo steel. The developments are classified under the headings: Introduction of steel compositions not normally used in such work; improvement of steel melting; ingot casting and ingot mould design; modifications in the forging operations; and the development of improved methods of heat-treatment.—B. G. B.

Two Way Press Produces High Pressure Parts. (*Steel*, 1953, **132**, Jan. 12, 66–69). Castings were not found satisfactory for parts of blow-out preventers and valves employed on deep oil well equipment. A special forging press was constructed by A. B. Farquhar Co. This press employs split dies operated by two 2000-ton horizontal rams and a main vertical ram of 5000 tons capacity. The press and some parts made with it are described.—R. A. R.

A Large Hydraulic Press and Draw-Bench Installation. (*Machinery*, 1953, **82**, Mar. 6, 433–435). A large hydraulic press, and a new design of hydraulically operated draw-bench have been installed at the Barberton works of Babcock and Wilcox Company, Ohio. This new equipment will enable large hollow forgings up to 35 in. in dia. to be produced with a maximum wall thickness of 4½ in. for subsequent manufacture into high-pressure boiler components.—E. C. S.

Flame Beats Sugar for Lengthening Die Life. J. A. Goodbar. (*Machinist*, 1953, **97**, Mar. 7, 384–386). High-silicon electrical grade steel was formerly heated to 170–200° C. and passed through a solution of 300 lb. sugar in 100 (U.S.) gall. of water before entering the machine for stamping into armature laminations. A coating of Carlite is now used and the strip passes through a small gas heater between the feed rolls and the die.—R. A. R.

Possibilities of Raising Seamless Tube Output by Improvements in the Drawing Method. B. Počta. (*Hutnik* (Prague), 1953, **3**, 2, 39–43). [In Czech]. On the basis of a detailed mathematical analysis of the drawing process involved in producing seamless tubes, recommendations are made which are likely to lead to more efficient tube manufacture in the temperature range 1250–1290° C.—P. F.

The Deformation Through the Die by Drawing of a Rod. H. Yamanouchi and I. Hayashi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 61). [In English]. Different die angles were used and results are given for strain in the direction of flow lines, radial and tangential strain, and shear strain.—K. E. J.

Stretch Forming. I. Forming Large Double-Curvature Skin Panels: The Avro Longitudinal Machine. II. Avro Practice

in the Manipulation of Rolled and Extruded Section: Rotary Preforming Machine. R. Wood. (*Aircraft Prod.*, 1953, **15**, Feb., 40–47; Mar., 82–89). Details of the construction of the Avro longitudinal machine are given with the aid of diagrams. Gripper jaws, forming dies, and forming technique are also described for the stretch-forming of fuselage and wing skin-panels. The Avro linear stretch-forming machine and the rotary preforming machine are also described, and the method of producing complex stressed forms is explained and illustrated.—T. E. D.

Pontiac Cold-Extrude Rocket Projectiles. B. C. Brosheer. (*Machinist*, 1953, **97**, Feb. 21, 301–303). One of the first successful applications of cold extrusion to the manufacture of steel parts on a production-line basis had been worked out by the Pontiac Motor Division of the General Motors Corp. for the production of 4·5-in. rocket nose pieces.—E. C. S.

The Extrusion of Steel—Equipment, Operation, Production. J. Sejournet. (*Iron Steel Eng.*, 1953, **30**, Jan., 73–77). This paper discusses the engineering aspects of steel making and processing. The underlying principles of successful extrusion of steel, the novel means of accomplishment now in use, and some possible future departures from present practices are dealt with.—M. D. J. B.

Sintered Carbide Wire-Drawing Dies. J. Höll. (*Hutník* (Prague), 1953, **3**, 2, 36–39). [In Czech]. The development, composition, and properties of wire-drawing dies, and methods of using them under various conditions and temperatures are discussed. Russian standard specifications relating to tolerances in carbide die dimensions are given, and the composition, physical properties, and particular applications of the sintered carbides employed in their manufacture are tabulated.—P. F.

Cutting Costs with Better Plant Layout. D. M. Schmid. (*Wire and Wire Prod.*, 1953, **28**, Feb., 159–165). Some examples of improved plant layout in wire mills are given.

Methods of Wire Production. K. V. Aiyer. (*Trans. Indian Inst. Met.*, 1951, **5**, 95–110). Recent advances in the practical aspects of wire drawing are surveyed. A short discussion of the plasticity theory for wire drawing is given in order to evaluate drawing tension. A simple method is indicated for calculating the power absorbed during drawing using flow curves, and this is illustrated by samples.—D. H.

Unique Non-Rotating Single Block Coiler and Non-Rotating Multiple-Block Take-up for Continuous Wire Processes. N. M. Hudak. (*Wire and Wire Prod.*, 1953, **28**, Mar., 269–270). The device is described and illustrated, and its advantages are cited.—J. G. W.

ROLLING-MILL PRACTICE

Some Conditions and Factors Influencing Rolling-Mill Efficiency. V. Kořínek. (*Hutník*, (Prague), 1953, **3**, 1, 14–17). [In Czech]. The manner in which rolling-mill performance is affected by changes in the staple product and the layout of mill stands is discussed.—P. F.

Electrical Equipment in Steel Plants. A. F. Kenyon. (*Blast Furn. Steel Plant*, 1953, **41**, Jan., 81–86; Feb., 192–197). A number of electrical drives for rolling mills in the U.S.A., either recently installed or in the planning stage, are described.

Functioning of a Lubrication Organization in Heavy Rolling Mills. R. R. Taylor. (*Iron Steel Eng.*, 1953, **30**, Jan., 107–110). The author puts forward a plan for organizing lubrication in rolling mills. The need and value of organized lubrication is stressed, and problems of management, labour, maintenance, and training of personnel are dealt with.—M. D. J. B.

Solved and Unsolved Problems Relating to the Mechanical Parts of Blooming Mills. G. Leder. (*Stahl u. Eisen*, 1953, **73**, Apr. 9, 470–480). Some of the components of blooming mills and the status of their development are discussed. Feeding the ingot to the rolls bottom-first has advantages over top-first feeding, but requires appropriate equipment. New designs of ingot tilters, roller tables, step rollers, and manipulators are compared. For balancing and screw-down gear, various designs have been used, but the superiority of any particular type is not established. Examples are quoted to show that scale removal in the blooming mill is possible with water spraying and the control of the amount of ingot cropping is discussed. A new method of rolling ingots in a modified mill train is described.—J. P.

Small 2-High Reversing Mills Gain Favour. E. C. Peterson. (*Steel*, 1953, **132**, Mar. 9, 115–123). The author explains why modern small 2-high reversing mills for rolling special semifinished steels are becoming increasingly popular. On many counts they are found preferable to the 3-high mill and forging hammer or press. Lower production costs and greater operating flexibility are the main advantages.—D. L. C. P.

Operation and Roll Design of the Gary Rail Mill. R. W. Dickson. (*Iron Steel Eng.*, 1953, **30**, Jan., 93–101). Improvements in rail rolling operations during the last 40 years at the Gary Works of United States Steel Co. are outlined and the present mill is described. Flat-bottomed rails of 118 lb./yd. are now rolled. There is a 4-stand, 40-in. tandem blooming mill, followed by a 3-high, 40-in. blooming mill stand with five passes. The 28-in. rail mill consists of a 3-high roughing stand, a 2-high forming stand, dummy stand, first and second edger stands, leader stand with rail head wheel, and finishing stand with rail foot wheel.—R. A. R.

The New Horse-Shoe and Fishplate Works at Gerlafingen. (*Roll'schen Eisenwerke Werkzeit*, 1953, **24**, Jan., 31–34). Details of the works layout and methods of handling the material are given.—E. C. S.

United Introduces Its Rendleman Rod Mill. N. Rendleman and A. Wilson. (*United Effort*, 1952, Sept.–Oct., 3–8). The design, layout and operation of the Rendleman rod mill are described in detail with a number of flow diagrams for rolling various rod sizes. It is claimed that the output approaches the equivalent of three single-strand mills.—P. C. P.

A Continuous Hot Mill for Medium Wide Strip. M. Langen. (*Brit. Steelmaker*, 1953, **19**, Mar., 136–143). Detailed information is given of the arrangement, design, and performance of the new continuous hot-strip mill at the Société Anonyme des Laminoirs, Hauts-Fourneaux, Forges Fonderies et Usines de la Providence in Eastern France. The mill produces strip up to 24 in. wide, with a maximum output of 100 tons/hr.

Design and Operation of Fully Continuous Mill Trains for Medium-Width Strip and Their Relation to Wide Strip Mills. K. Wallmann. (*Stahl u. Eisen*, 1953, **73**, Mar. 26, 394–400). The steadily increasing demands from the fabricating industry on the uniformity and surface finish of strip steel are outlined: these demands can be met only by the fully continuous mills. Medium-width rolled strip has certain advantages over that made by slitting wide strip, particularly in the shape which can be given to the edge. Two American mill train designs are discussed and the differences between these and wide strip mills are indicated. The modern medium strip mills at La Providence (Réhon) and Corby (Stewarts and Lloyds, Ltd.) are described.—J. P.

Regulation Systems—The Key to Higher Production. W. R. Harris. (*Blast Furn. Steel Plant*, 1953, **41**, Mar., 302–306). The use of automatic regulating systems to control the speed of rolling mills and an automatic tinplate line is discussed. A magnetic-amplifier system (the 'Magamp') for a tandem cold-reduction mill drive is considered.—B. G. B.

'English Electric' Equipment at the Abbey Works of the Steel Company of Wales. I. Twin Motor Drive for 45 inch Slabbing Mill. H. S. Brown. (*English Elect. J.*, 1952, **12**, Sept., 3–18). The slabbing mill provides the material for the rest of the mills at the Abbey Works to work upon, receiving ingots up to 20 tons and rolling them to slabs of varying thickness and width, the minimum thickness being 5 in. and the maximum width 60 in. A double armature design and the Ilgner set were chosen. Four motor armatures and four generators were decided upon. In an emergency, this system permitted two generators to be disconnected and the mill run on the remaining generators at half speed but with full torque available.—J. C. B.

'English Electric' Equipment at the Works of the Steel Company of Wales. II. Main Drives for 3-Stand Cold Strip Mill. G. R. Wilson. (*English Elect. J.*, 1952, **12**, Dec., 34–42). The last stage in the process of rolling down to strip gauges at the Abbey Works is effected in the 80-in. wide 3-stand cold strip mill. The proposed weekly throughput of steel strip and sheet is 7000 tons. Each stand has its own double-armature motor with an independent speed range, and the total power, including the reel drive motor, is 13,000 h.p. (R.M.S.). This article describes the control systems, circuits, exciter sets and auxiliaries, and also ventilation, in detail.

'English Electric' Equipment at the Abbey Works of the Steel Company of Wales. III. Equipment for Power Supply Control and Distribution. J. F. Smith. (*English Elect. J.*, 1952, **12**, 9, Dec., 43–48). A 66-kV. outdoor substation of the South Wales Electricity Board at Margam provides the

largest part of the power supply for the Abbey Works. It comprises a single bus-bar arrangement incorporating eleven air-blast circuit-breakers controlling three incoming feeders, two bus-sections and six transformers. There are three sets of 11 kV. switchgear installed in the works in separate switchrooms, each controlling a 4500-h.p. synchronous motor for the roughing drives of the hot strip mill.—J. C. B.

MACHINERY FOR IRON AND STEEL PLANT

The Development of Weighing Machines for the Iron and Steel Industry. K. Rosenbaum. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 573–574). The operation of automatic wagon weighing machines is briefly described.—J. P.

Direct or Alternating Current for Steelworks' Cranes? H. Renker. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 525–528). In spite of the excellent properties of D.C. motors, conditions in German steelworks have led to the increasing use of A.C. crane motors. This development has been made possible by improvements in the control of A.C. motors. The Eldro brake control simplifies many problems and increases operational safety. The D.C. motor has not been superseded; it must still be employed for heavy duty.—J. P.

Electrical Equipment of Cranes for Service in Iron and Steel Works. H. Enke. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 528–536). Operational control of cranes can be made reliable by extensive simplification and standardization. Even with A.C., operational and control requirements in steelworks may be met. Operational safety can be increased by the use of semi-automatic switchgear which acts independently of the skill or choice of the crane driver.—J. P.

Recent Developments in the Design of Iron and Steel Works' Cranes. H. Ernst. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 538–545). Recent developments are discussed. Further improvements are possible given adequate collaboration of constructional and electrical engineers and works' management.—J. P.

Innovations in the Design of Cranes and Efforts to Rationalize their Construction. E. Kemna. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 545–553). The general basis of modern crane design and its development are outlined and some novel systems are described. The significance of efforts to improve and simplify construction and the obstacles encountered are discussed. Future developments require the close collaboration of constructional and steelworks' engineers.—J. P.

The Productivity of Modern Plate Shears. (*Mét. Constr. Mécan.*, 1952, **84**, Dec., 941–943). A cost analysis of the operation of two plate shears, one typical of those in current use, the other of very modern design, is presented. A considerable yearly saving is shown by using the modern machine.

Application and Control of A.C. Motors on Intermittent Loads. R. H. Wright. (*Iron Steel Eng.*, 1953, **30**, Jan., 65–71). The author describes recent developments in the design of A.C. drives for intermittent loads to eliminate flywheels, to reduce variations in reactive kVA., and to reduce violent load fluctuations. Details are given of a new liquid slip regulator developed to overcome the weight, bulk, and inefficiency of the cooling system of older types.—M. D. J. B.

Engineering Maintenance: B.I.S.R.A. Conference. (*Iron Steel*, 1953, **26**, Feb., 56–58). The proceedings of a B.I.S.R.A. conference on engineering maintenance in the iron and steel industry are summarized. The particular aspects considered are: Plant recommendations for the future, relation of production and maintenance departments, preventive maintenance, and manning problems.—G. F.

LUBRICANTS AND LUBRICATION

How to Use Molybdenum Disulphide As a Lubricant. L. M. Davison. (*Machinist*, 1953, **97**, Feb. 14, 266–268). The theory of lubrication is briefly considered and details of experience with arbors, bearings, conveyor chains, motor springs, deep drawing and machining operations are given.—E. C. S.

Grease, Wide Temperature Range. G. Kinner, D. S. Marshall, and D. M. Duckworth. ('*Lubricants and Lubrication*,' *Selected Government Research Reports*, 1952, **11**, 184–198, Report No. 16). A description is given of the development of a lubricating grease having a wider useful working temperature range than had hitherto been obtained with standard specified grades.—R. A. R.

An Investigation into Methods of Measurement of Kinetic Boundary Friction. P. G. Forrester and A. A. Milne. ('*Lubricants and Lubrication*,' *Selected Government Research Reports*, 1952, **11**, 207–230, Report No. 19). Using metal combinations of mild-steel/mild-steel, hard-steel/bronze, Babbitt/bronze, and cast-iron/cast-iron, investigations were carried out in different types of machine on similar specimens prepared in different ways. The results for similar materials showed that friction values for oils and surfaces were placed in the same order of magnitude, the absolute values for the coefficient of friction differed. The causes of these differences are examined.—R. A. R.

The Coefficient of Friction of Lubricated Sliding Surfaces. G. Niemann and K. Banaschek. (*Z.V.d.I.*, 1953, **95**, Feb. 21, 167–173). Results of measurements on a disc rotating between two hemispherical sliders are reported.—J. G. W.

Investigations of the Behaviour of Metal and Plastic Slides. (Production Engineering Res. Assoc.: *Machinery*, 1953, **82**, Feb. 22, 405–409). **Developments in Plastic and Metal Slide Research.** (*Machinist*, 1953, **97**, Feb. 7, 205–209). **Developments in the Study of Metal and Plastic Slides.** (*Machine Shop Mag.*, 1953, **14**, Feb., 75–80). Some recent developments in materials and lubricants are summarized.—E. C. S.

WELDING AND FLAME-CUTTING

The Nature of Heat in the Welding Process. R. T. Howard. (*Welding J.*, 1953, **32**, Feb., 127–131). The author discusses the thermodynamics and physics of the welding arc and the heat effects on metallurgical properties.—U. E.

Relation of Preheating to Embrittlement and Microcracking in Mild Steel Welds. A. E. Flanigan and T. Micleu. (*Welding J.*, 1953, **32**, Feb., 99s–106s). Embrittlement affecting mild steel arc welds is studied. In the case of welds which normally exhibit micro-cracking when deposited at room temperature, it was found that preheating improved the bend-test ductility. In the case of welds not subject to microcracking, preheating was very much less beneficial.—U. E.

Casting Design Improved by Welding. A. L. Phillips. (*Foundry*, 1953, **81**, Feb., 148, 151). The advantages and applications of ' cast/weld ' constructions are briefly reviewed with particular reference to the use of the ' ChamferTrode ' and ' SteelTectic ' tools.—L. E. W.

Welded Structures for Iron and Steel Works. F. W. Griese. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 556–567). The precautions that must be observed in changing from riveted to welded construction are discussed. Welding often necessitates modification of the original design so as to take into account strength factors, particularly the elastic behaviour of components. Many examples of welded structures are illustrated.

Repair Welding in Iron and Steel Works. W. Klapheck. (*Stahl u. Eisen*, 1953, **73**, Apr. 23, 568–572). Repair welding is an important auxiliary in iron and steel works for the reconditioning of damaged and worn components. Its use can lead to considerable savings because rapid repair keeps idle periods to a minimum.—J. P.

Welding Heavy Sections of Mild Steel. R. R. Roberts. (*Welding Metal Fab.*, 1953, **21**, Feb., 63, 68). A brief summary is made of recent data on micro-cracking in weld metal and recommendations are given to overcome these failures. If the recommendations are carried out, trouble-free welding of mild steel in thicknesses greater than 1½ in. will be ensured.

Welding Under a Tensile Load. H. Melhardt. (*Schweisstechn.*, 1952, **6**, Dec., 133–141; 1953, **7**, Jan., 6–11). A new method has been developed in which welding can be carried out on girders in tension, *i.e.*, on bridges. The method is based on the assumption that the variation in stress distribution in a girder in tension during welding can be controlled by suitable temperature distribution. This can be achieved by inserting thin asbestos sheets into small vertical cuts, thus preventing heat flowing to other parts of the girder. The method was tested experimentally and stress and strain measurements were carried out.—U. E.

The Manufacture of Hot and Cold Finished Seamless and Welded Steel Tubing. J. Porteous and P. L. Cotton. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 217–241). The continuous-weld pipe process is reviewed, and the furnaces, mill, and flying-saw are treated in more detail.—J. C. B.

Experiences with the Oxy-Acetylene Pressure Welding of Rails. W. Hoffmann. (*Schweissen u. Schneiden*, 1953, **5**, Mar., 90–95). The pressure welding of steel rails is discussed. Correct temperature and pressure relations are presented graphically and the physical properties of the welded steel rails are studied.—U. E.

Modified Flash Butt Welding of Rails and Sleepers. O. Wendt. (*Schweissen u. Schneiden*, 1953, **5**, Mar., 99–104).

A modified version of the flash butt welding process is described.—U. E.

Welding of Rails by the Thermit Process. F. Gessner. (*Schweissen u. Schneiden*, 1953, **5**, Mar., 95–99). The Thermit welding process as applied to the welding of steel rails is described. Micrographs of the weld and adjacent zones are given. The economics of the process are discussed.—U. E.

Blowholes in Weld Seams. W. Hummitzsch. (*Schweisstechn.*, 1953, **7**, Jan., 1–6). The physical chemistry of gas reactions which occur during arc welding is discussed. The calculation of total gas pressures from partial pressures shows that the pressure is not high enough to form blowholes.—U. E.

The Welding of Mild Steel to Cast Iron. C. C. Bates. (*Trans. Inst. Weld.*, 1953, **16**, Feb., 5–11). The welding of mild steel studs to grey cast-iron members was studied and a welding procedure evolved. The effects on the physical properties obtainable by fillet welds with and without " buttered pads " were studied.—U. E.

Avoidance of Blowholes when Welding Cast Iron. (*Foundry Trade J.*, 1953, **94**, Feb. 26, 245–246). The procedure for producing a cast-iron weld free from blowholes is described.

Welding of Malleable Iron. F. Roll. (*Schweissen u. Schneiden*, 1953, **5**, Feb., 70–74). The metallurgy of white and black-heart malleable cast irons is discussed. Properties and recommendations for welding are given in a chart.—U. E.

Resistance Welding of Cold-headed Bolts. J. E. Roberts. (*Welding Res.*, 1952, **6**, Dec., 118*r*–124*r*). The development of a design of bolt head for projection welding to sheet material (from 12 to 20 S.W.G.) is described. Use has been made of statistical techniques in the experimental work, to compare the effects of factors involved in welding, especially of bolt-head contour. Provisional standard bolt head designs for $\frac{5}{16}$-in. bolts were developed and used in electrode life tests. Over 6000 welds were made without any deterioration in weld strength or consistency, and without dressing the electrodes.—U. E.

Structural Formations and Changes in Properties of Heat-Resisting Chromium–Molybdenum Steels during Arc Welding. T. Norén. (*Jernkontorets Ann.*, 1952, **136**, 12, 511–548). [In Swedish]. The necessity for preheating and/or stress-relieving of work was studied in this investigation which sought to establish sound welding conditions and obviate the risk of brittle cracking when welding creep-resistant steels. Weldability of these steels (C 0·15%, Cr 1%, Mo 0·4%) is discussed on the basis of the austenitic transformation and notch sensitivity of the weld metal and heat-affected zone. Graphitization problems and oxidation resistance are examined. Brittle cracking is avoided by a ferrite–bainite structure and the critical cooling rate, given by a modified TTT diagram, based on continuous cooling, is apparently 8–9 mm. Jominy distance. Welding without preheating can be carried out with 2·5 mm. electrodes for the first run in **V** joints with plates up to 10 mm. thick. Above this thickness martensite must be suppressed by preheating up to 150–250° C.—G. G. K.

Selection and Evaluation of Methods of Hard Facing. J. J. Barry. (*Welding J.*, 1953, **32**, Feb., 119–126). Methods of application of hard-facing materials, with particular emphasis on the use of the inert-gas-shielded arc, are discussed.—U. E.

Arc Welding of Chain Links. A. Buchholz. (*Schweissen u. Schneiden*, 1953, **5**, Feb., 66–70). The metallurgical properties of arc-welded heavy chain have been studied.—U. E.

Cold-Pressure Welding as Novel Joining Method. W. Hofmann and J. Ruge. (*Z.V.d.I.*, 1953, **95**, Mar. 11, 233–237). An investigation of cold pressure welding is reported. Clean surfaces are essential for good welds, but the time interval between cleaning and welding, and compression rate had no influence on weld quality. Pressure welding of steel is possible but is not a practical proposition.

The Technology of Automatic Welding in the Soviet Union—Recent Advances. J. Mannin. (*Engineers' Digest*, 1953, **14**, Jan., 14–17).

MACHINING AND MACHINABILITY

Testing the Machinability of Materials Used in Mass Production. P. Wiest and G. Wagner. (*Jernindustri*, 1952, **33**, 11, 252–259). [In Norwegian]. A great need is apparent for material quality gradings based on machinability. The chip-forming test is liable to be influenced by many variables. A short-time test is described in which the cutting speed is regularly increased from a predetermined initial value until the tool cutting edge (1% C, 5% W in the case of samples containing less than 0·4% C) breaks down. The maximum cutting speed achieved is a basis for calculating relative machinability. Results of tests on 48 American and German steels and their machinability indices are tabulated.—G. G. K.

The Machinability of Metals and the Wear of Tools. M. C. Shaw. (*Rev. Univ. Mines*, 1953, Series 9, **9**, Apr., 159–172). The importance of the problem of cutting metals and the theories proposed to explain the formation of metal chips are discussed. A new technique for measuring the wear of tools by observing the progressive disappearance of diamond impressions made on the tool face is described. Results obtained are reported and discussed.—B. G. B.

Metallurgical Aspects of Machinability of Steel. W. I. Pumphrey. (*Welder*, 1952, **29**, July–Sept., 63–68; Oct.–Dec., 85–90). In the first part the author explains the difficulty of defining and estimating the machinability. Seven tests are enumerated to give some measure of machinability. Wragge's empirical formula connecting cutting speed with the dimensions of the chip formed and tool life is quoted. There follows a discussion on chip formation and its attack on the tool.

Relative Abrasiveness of the Last Surfaces of Various Gray-Iron Castings on Single-Point Tools of High-Speed Steel. J. Datsko and O. W. Boston. (*Trans. Amer. Soc. Mech. Eng.*, **75**, Jan., 103–108). Plain grey iron castings, sand-cast, have an abrasive surface resulting in low tool life on machining. This can be eliminated by pickling the castings before machining. Annealing improves machinability but results in more pronounced skin effects.—D. H.

The Significance of the Thermal Number in Metal Machining. B. T. Chao and K. J. Trigger. (*Trans. Amer. Soc. Mech. Eng.*, 1953, **75**, Jan., 109–120). A theoretical analysis of heat flow in conjunction with cutting data in high-speed orthogonal metal machining operations reveals that, for a given tool rake, temperature distribution along the shear plane is solely dependent on the thermal number $V_c t/k$ where V_c is the cutting velocity, t the chip thickness, and k the thermal diffusivity of the work material.—D. H.

Electrolytic Grinding. L. H. Metzger and G. Keeleric. (*Machinist*, 1953, **97**, Feb. 21, 304–308). A method for the electrolytic grinding of carbide tools is described. It makes use of, but is said not to consume, diamond bort. A special machine has been built for the purpose although existing equipment can be converted. Other metals can be ground.

CLEANING AND PICKLING

Descaling Stainless Steel Tube—Use of the Sodium Hydride Process by Accles & Pollock Ltd. N. L. Evans. (*Iron Steel*, 1953, **26**, Apr., 134–136). The sodium hydride process for descaling stainless steel tubes has been used at the works of Accles and Pollock Ltd. for two years. A description of the plant and process is given and its value is assessed. Its outstanding features are speed, complete absence of attack on the metal, conservation of alloying elements, and saving of labour.—G. F.

Cold Cleaner Cuts Costs. D. C. Miner. (*Steel*, 1953, **132**, Mar. 16, 100–101). A new combination of alkali-solvent wetting agent applied cold through power washers is reported to be preferable to hot methods for many lighter cleaning jobs.—D. L. C. P.

Mechanical Cleaning Gives Higher Luster at Lower Cost W. G. Patton. (*Iron Age*, 1952, **170**, Dec. 11, 155–157). The mechanical scouring of steel strip developed by the Minnesota Mining and Manufacturing Co. is being used as a surface conditioner for stainless steel. Silicon carbide paper is fed continually under pressure over the scouring rolls at 3 to 6 in./min. with strip speed ranges from 50 to 200 ft./min. and both sides are scoured at once. Stains, oil films, oxides of all types, and other surface defects are removed.—A. M. F.

The Oxidation of Ferrous Hydroxide. J. E. O. Mayne. (*J. Chem. Soc.*, 1953, Jan., 129–132). The composition has been examined of the air-dried material produced by addition of alkalis to ferrous sulphate solution. When the pH was low, γ–$Fe_2O_3.H_2O$ was obtained; in more alkaline solutions, α–$Fe_2O_3.H_2O$ was formed when the oxidation was fast, and a material having a composition between Fe_3O_4 and γ–Fe_2O_3 formed when it was slow. The results are explained in terms of the oxidation and hydrolysis of a basic sulphate.—J. C. B.

Metal Recovery by Ion Exchange. C. F. Paulson. (*Plating*, 1952, **39**, Dec., 1330–1334, 1338). Some methods are described by which metals (as cations or combined as anions) may be

removed from waste and rinse waters by treatment on ion exchange beds. The process may serve to recover valuable materials or as an alternative to conventional treatments to render waste water fit for disposal.—J. P.

PROTECTIVE COATINGS

The Manufacture and Properties of Clad Steel Plates. T. T. Watson. (Amer. Iron Steel Inst.: *Blast Furn. Steel Plant*, 1953, **41**, Mar., 318–320, 326–327, 351, 354–355). Methods of fabricating clad steel plates and sheets are described. The bonding surfaces must be thoroughly cleaned. In the case of stainless and Inconel clad steels, the surface layer of chromic oxide must be removed if a satisfactory bond with carbon steel is to be obtained. Details of the treatment used in this case are given. The physical properties of clad steel plates are considered in some detail and tables and graphs of properties are given.—B. G. B.

Coatings for Steel Water Pipe. W. H. Cates. (*J. Amer. Water Works Assoc.*, 1953, **45**, Feb., 103–112). The necessary qualities of effective coatings are outlined and the properties of the available materials are discussed. Costs of protecting pipes related to estimated useful life are tabulated. (15 references).—T. E. D.

Product Finishing by Metallic Deposition *in Vacuo*. R. H. Warring. (*Mech. World*, 1952, **132**, Dec., 276–280). Brief details are given of the plant required to carry out metallic deposition *in vacuo*. The process depends on highly specialized plant, but in operation it is quick and simple. Some applications of the technique are given.—D. H.

Clear Protective Coatings over Chromium Plate Systems. G. L. Poy. (*Precision Met. Mold.*, 1952, **10**, Nov., 38–42). The author discusses the use of clear protective coatings of synthetic enamel and lacquer, and solvent soluble films. These coatings, when applied to copper and flash-chromium plated articles afford significant protection.—D. H.

Chromizing. S. Ueda. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 59–60). [In English]. Under similar conditions, the chromium powder process produces a thicker layer, but the $CrCl_2$ process gives better surface results. Added Al_2O_3 improves the powder process, particularly at high temperature; NH_4Cl is of doubtful efficacy. For good results, 2–3 hr. at 1000° C. are needed. Chromizing becomes more difficult as carbon content increases.—K. E. J.

Notable Advances in Fabrication Methods and Metal Applications. T. Bishop. (*Metal Progress*, 1953, **63**, Jan., 115–119). Surface diffusion processes have been the subject of considerable investigations and the author discusses the chromizing of steel. The scarcity of certain alloying elements has led to extensive investigation into substitutes for the established tool steels. The precision casting of hard materials for dies has been developed to a stage where sufficient accuracy can often be obtained without having to machine the casting.

Effect of Impurities and Purification of Electroplating Solutions. I—Nickel Solutions. 6. The Effects and Removal of Iron. D. T. Ewing, A. A. Brouwer, and J. K. Werner. (*Plating*, 1952, **39**, Dec., 1343–1349). Iron at concentrations of 0–200 p.p.m. in nickel plating baths has no great deleterious effect on the adherence, ductility, or corrosion resistance of the deposits. Iron in the high-*p*H Watt's bath may precipitate and cause roughness. Chemical and electrolytic methods are described for removing iron from solution.—J. P.

Hot-Dip Galvanizing of Nails. A. Gordet. (*Mét. Constr. Mécan.*, 1952, **84**, Oct., 739–741; Dec., 965–969). Methods for galvanizing nails are discussed. Details are given by the author of a process which he has found to be satisfactory. The stages of degreasing, pickling, washing, fluxing, preheating, galvanizing, and quenching are described.—B. G. B.

Design of an Oil-Fired Galvanizing Furnace. W. D. Bawden. (*Wire and Wire Prod.*, 1953, **28**, Feb., 151–154, 222). An account is given of the steps in designing an oil-fired galvanizing furnace for processing wire cloth and wire netting at the Gilbert and Bennett Manufacturing Co., Georgetown, Conn.—J. G. W.

Development of Electroformed Copper–Steel Wire. A. N. Gray. (*Wire and Wire Prod.*, 1953, **28**, Feb , 166–168, 218–219). Particulars are given of an electroplating plant developed at the Western Electric Co., Baltimore, for the manufacture of copper-clad steel wire for telephone transmission. The treatment is continuous, 25 wires passing through nine different chemical processes and 32 separate treatments, the average length between supply and take-up being 850 ft. Rate of copper deposition is controlled by a device, based on the Kelvin bridge, for continuously measuring the resistivity.—J. G. W.

Practical Spray Applications of Synthetic Resin Enamels. (*Indust. Finishing*, 1953, **5**, Feb., 492–494). Conditions are described for obtaining the best results. These concern selection of thinners and plasticizers, metal surface preparation, priming, baking, and final finishing. Modifications of the operations are needed for direct application of enamels.

"Pinholing" and "Boiling" in Enamelled Light-Iron Castings. E. Holland. (*Foundry Trade J.*, 1953, **94**, Mar. 5, 273–279). This article records a trial-and-error approach which has been made in the foundry to deal with the problems of 'pinholing' and 'boiling' in enamelled light-iron castings. The incidence of 'pinholing' is reduced by steady pouring without swilling, and having hot metal and smooth-flowing runners. 'Boiling' is due to the pick-up to a depth of about 0·002 in. of ferrous sulphide which reacts with the enamel.

Vertical Furnace for Enamelling. (*Metallurgia*, 1953, **47**, Mar., 145–146). A recent continental installation incorporating two tower-type furnaces is described. The furnace used is continuous and reversible. It is designed and built by G. Ruhstrat, Göttingen; it requires little floor space and is suitable for a wide range of articles of different sizes.—B. G. B.

Pyrophyllite in Refractory Enamels. J. Bishop. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Dec., 493–496). The value of pyrophyllite in developing a coating which would offer protection from oxidation of low carbon steel at operating temperatures higher than those organic coatings can withstand was investigated. The application of a dry pressed coating to metal by a low temperature frit gave good adherence, and has possibilities in uses where flat surfaces are involved. The composition of a good enamel is given.—E. C. S.

Production Costs Lowered with Pre-Coated Coil Stock. A. E. Uhleen. (*Iron Age*, 1952, **170**, Dec. 18, 145–147). Coils of strip pre-coated with enamel or lacquer are now being used in a wide variety of light fabricating operations. Stamping, piercing, embossing, and deep drawing can be performed without damage to the surface which can have a film thickness of 0·00005–0·002 in. Considerable savings on final productions costs are claimed.—A. M. F.

Paints and Varnishes for the Protection of Metals. M. Massard and R. Studler. (*Usine Nouvelle*, 1953, **9**, Feb. 12, 23–29). Recent developments in the compounding of paints and varnishes for protecting metal surfaces are surveyed. The importance of surface preparation is mentioned, and the combination of either chemical surface treatment or metallic coating and suitable varnishes is described. Methods of applying paints and varnishes, drying, and baking are outlined.—T. E. D.

POWDER METALLURGY

Considering Powder Metallurgy. H. W. Greenwood. (*Engineer*, 1953, **195**, Feb. 20, 269–270). The author believes that powder metallurgical technique could be used with advantage to a much greater extent than at present, owing to changing conditions and prices, and cites examples of applications. An increased use of powder metallurgy is anticipated in the production of new high-temperature resistant materials for use in turbines and jet engines.—J. McK.

Sintering Characteristics of Iron–Zinc Powder Blends. A. A. Krishnan. (*Trans. Indian Inst. Met.*, 1951, **5**, 271–281). The concept of sintering is explained as the process of bonding of solid bodies under pressure and temperature. In the case of iron–zinc powder mixtures, the process was studied and results were obtained for dimensional and volume changes, changes in weight, density, and hardness. There exists a linear relationship between the absolute equilibrium temperature of sintering of 'no change' and the percentage of zinc in the compacts.—D. H.

Development of a New Self-Coated Corrosion Resistant Porous Body. A. A. Krishnan. (*Trans. Indian Inst. Met.*, 1951, **5**, 283–293). Various iron–zinc compositions (Zn up to 50%) were sintered at between 872° and 1095° C. in hydrogen or carbonaceous atmospheres. Tests on sintered compacts were made for hardness, porosity, permeability, shape, pore size, and the corrosion resistance of their 'sweat-out' coating. The compacts gave permeable samples. The coating of zinc obtained by controlling the sintering cycle gave ample protection against corrosion of the samples. The new 'sweatout'

process produced in one operation an internally and externally self-coated corrosion-resistant porous body which could be used as a bearing, filter or heat exchanger.—D. H.

Progress Report on Hot Forging Pre-Alloyed Metal Powders. L. H. Mott. (*Precision Met. Mold.*, 1952, **10**, Oct., 38–39). Details are given of the hot coining technique for the production of dense parts in pre-alloyed powders. Brief mention is made of the various stages in the process under the headings, briquetting, heating, coining, and finishing. Hot coining is claimed to give physical properties and response to heat-treatment identical with, or superior to, the same material fabricated by conventional means.—D. H.

Iron Powder Pinion Out-Performs Cast Iron. (*Precision Met. Mold.*, 1952, **10**, Oct., 33). Details are given of the substitution for machined cast iron whee drive pinion for a lawn mower of a case-hardened powder-fabricated pinion (composition 80/20 iron and brass powders).—D. H.

Floating Die Table Equalizes Press Action. G. Karian. (*Iron Age*, 1952, **170**, Dec. 25, 78–80). The action of a floating die table and a descending upper punch have been applied to punch press design to produce the same compressive forces obtained with a dual-punch press. The pressure created between the upper and lower dies is applied to powdered metal particles to form a part of uniform density throughout. Presses equipped with a floating die table can form pieces of relatively deep elevation. Application of this method avoids the excessive expense for a dual-punch press of a large size.

PROPERTIES AND TESTS

Report on ASTM Task Group for Determination of Elastic Constants. W. Ramberg. (*Symposium on Determination of Elastic Constants, Amer. Soc. Test. Mat. Special Technical Publication* 129, 1952, 3–9). The task group was appointed to survey the work done in determining the elastic constants of materials and to recommend suitable methods for the determination of elastic moduli. Answers to a questionnaire on the subject are reviewed.—B. G. B.

The Influence of Temperature on the Elastic Constants of Some Commercial Steels. F. Garofalo, P. R. Malenock, and G. V. Smith. (*Symposium on Determination of Elastic Constants, Amer. Soc. Test. Mat. Special Technical Publication* 129, 1952, 10–30). Elastic moduli in tension and in shear have been determined at various temperatures between 75° and 1500° F. for 21 commercial steels, both carbon and alloyed. With increasing temperature, both the tensile and shear moduli decrease approximately linearly until a certain temperature is reached, beyond which a more rapid decrease is observed. This temperature is 700°, 900°, and 1300° F. for carbon, alloyed ferritic, and austenitic stainless steels respectively. Poisson's ratio does not change significantly with temperature.—B. G. B.

Dynamic Methods for Determining the Elastic Constants and Their Temperature Variation in Metals. M. E. Fine. (*Symposium on Determination of Elastic Constants, Amer. Soc. Test. Mat. Special Technical Publication* 129, 1952, 43–70). Dynamic methods of measuring the elastic constants, in which the specimen is part of a vibrating system (ranging in frequency from a fraction of a cycle to 30 megacycles/sec.), are critically reviewed. Besides giving engineering information, dynamic-elastic measurements have proved of value in investigating solid state phenomena in metals.—B. G. B.

An Evaluation of Several Static and Dynamic Methods for Determining Elastic Moduli. J. T. Richards. (*Symposium on Determination of Elastic Constants, Amer. Soc. Test. Mat. Special Technical Publication* 129, 1952, 71–100). As a means of evaluation, modulus investigations have been conducted by several laboratories on three samples of beryllium copper rod. Static tests included tension, compression, flexure, and torsion. Dynamic moduli were obtained directly by speed-of-sound determinations, and indirectly from longitudinal, flexural, shear and torsional vibration. An explanation of the differences on the basis of the test methods used and the conditions of the test is attempted.—B. G. B.

Stress-Concentration Factors for Single Notch in Flat Bar in Pure and Central Bending. M. M. Leven and M. M. Frocht. (*J. Appl. Mech.*, 1952, **19**, Dec., 560–561). Graphs express the results of photoelastic determinations of stress-concentration factors in terms of three parameters r/d, D/d, and α, where r is the radius at the root of the notch, D is its overall depth, d is the minimum depth of the beam, and a is the notch or flank angle. For central loading, the length of the beam is also relevant.—E. T. L.

The Relationship between Chemical Composition and Notched-Bar Impact Strength after Ageing of Rimming Steels. H. Knüppel and K. Mayer. (*Stahl u. Eisen*, 1953, **73**, Mar. 26, 401–409). A statistical analysis of results of the notched-bar impact test after ageing shows that the ageing behaviour of steel depends on its chemical composition and only very slightly on its method of manufacture. Nitrogen, phosphorus, and oxygen have the greatest influence, and a mathematical relationship to describe their effects is given.—J. P.

Notch Bar Testing and the Selection of Steel for Welded Construction. W. Barr and I. M. Mackenzie. (*Symposium on Notch Bar Testing and Its Relation to Welded Construction*, Dec. 5, 1951, 7–10: Inst. Welding, 1953). The authors consider the use of notch bar tests for determining the suitability of steels for welded construction, and discuss the results of laboratory tests. By application of simple laboratory tests for notch ductility the steelmaker has been able to provide steels suitable for large monolithic welded structures. Unexplained instances of brittle fracture are now rare, and acceptance tests for notch ductility should be introduced into specifications with discretion.—B. G. B.

The State of Stress and Brittle Fracture. W. Soete. (*Symposium on Notch Bar Testing and Its Relation to Welded Construction*, Dec. 5, 1951, 19–27: Inst. Welding, 1953). The results of a series of investigations to study: (1) The variation in the ductility of the metal as a function of temperature; (2) the variation in the state of stress of a cylindrical notched test piece during loading; and (3) the variation of the ductility of the metal in relation to the state of stress and the temperature, are reported and discussed.—B. G. B.

Notch Bar Tests in Relation to Service Performance. C. F. Tipper. (*Symposium on Notch Bar Testing and Its Relation to Welded Construction*, Dec. 5, 1951, 29–33: Inst. Welding, 1953). The more important factors that must receive attention in relating small-scale tests to full-scale structures are discussed. The most important are the criterion of defining brittleness and the effect of dimensions. Since fracture appearance is the essence of a brittle fracture in service, a test which produces a similar fracture under approximately the same conditions of stress and temperature is considered to be a better guide to the suitability of a material than those where no attempt is made to do so. The results obtained on large built-up structures have proved disappointing as tests for the materials.—B. G. B.

Development of a Testing Method on Brittle Fracture of Mild Steel Plates. J. H. van der Veen. (*Symposium on Notch Bar Testing and Its Relation to Welded Construction*, Dec. 5, 1951, 35–43: Inst. Welding, 1953). The development is described of a notched-bar slow bend test for the determination of the tendency of steel plates to brittle fracture. Slow bending enables the recording of load-deflection diagrams to be made. The results obtained under these conditions are compared with those of other methods.—B. G. B.

An Inquiry into the Reproducibility of Impact Test Results. H. L. Fry. (*Amer. Soc. Test. Mat. Bull.*, 1953, Jan., 61–64). The investigation consisted mainly of performing a large number of tests on various materials using five impact machines, with all variables controlled. Most of the work was done on keyhole-notch Charpy specimens, but Izod and **V**-notch Charpy specimens were also studied. Wide variations in results were found, but the reason for this has not been determined. Differences were not due to errors of calibration.

The Structure of Cold-Worked Steels. E. G. Ramachandran. (*Trans. Indian Inst. Metals*, 1951, **5**, 187–214). The author has examined the effect of cold work on the physical and mechanical properties of steel. Details are given of dilation, hardness, magnetic, and thermal tests, and explanations are offered. The effect of cold work on ferrite is grain fragmentation and the inducement of a preferred orientation, on cementite it is also fragmentation and lattice distortion accompanied by transformation.—D. H.

Influence of Strain Gradient on Brittle Coating Sensitivity. A. J. Durelli and S. Okubo. (*Product. Eng.*, 1953, **24**, Jan., 136–137). This article deals with some new developments in the study of the influence of the strain gradient perpendicular to the crack on the failure of a brittle coating. The tests were conducted with 'Stresscoat' and the strain gradients produced were equivalent to 1500–6000 lb./sq. in./in.

in steel. Curves for correcting for stress gradient effects between these limits are given.—A. M. F.

Practical Measurements with Electrical Resistance Strain Gauges. K. Fink and Ch. Rohrbach. (*Z.V.d.I.*, 1953, **95**, Mar. 21, 265–273). The use of electric resistance strain gauges in static and dynamic problems is discussed with several examples of its use, including the measurement of roll force and rolling torque, checking loads in fatigue testing machines, and measuring loads in presses.—J. G. W.

Foil Strain Gauges. (*Engineer*, 1952, **195**, Mar. 13, 398). Uses and advantages of strain gauges, made by using the 'printed electric circuit' technique to produce a very thin copper–nickel foil on a lacquer base, are described. Results of tests to determine sensitivity are given.—J. MCK.

The Continuous Determination of a State of Residual Stress in Metallic Solid and Hollow Cylinders. H. Bühler. (*Z. Metallkunde*, 1952, **43**, Nov., 388–395). Electrical resistance strain gauges are used in the determination of residual stresses in steel and brass hollow and solid cylinders, both boring and turning-down techniques being employed. The method of calculating three-dimensional residual stresses is given, and the formulæ for calculating the stress components are derived.—L. H.

Fatigue Tests on Defective Butt Welds. W. G. Warren. (*Welding Res.*, 1952, **6**, Dec., 112*r*–117*r*). An investigation of the effect of certain weld defects on the fatigue strength of butt-welded mild steel plates is reported. The relationship between alternating stress and number of cycles shows that a reasonably firm fatigue limit can be determined for the specimens showing 'cracks' and 'lack of penetration.' It is therefore possible to correlate the performance under fatigue loading of a welded joint containing internal flaws with the appearance of its radiograph when the flaw has the nature of a crack or lack of penetration, but not of a slag inclusion.—U. E.

Fatigue of Ferrous Metals—A Phenomenological Approach. H. L. Cox. (*Iron Steel*, 1953, **26**, Feb., 45–50). The author reviews experimental work on the fatigue of ferrous metals and summarizes the present state of knowledge regarding the fatigue strength of steels. The evidence indicates that the true criterion of fatigue strength concerns some average stress value throughout some small volume, and not at a single point, so that fatigue strength is influenced by the stress gradient in the region of maximum stress.—G. F.

The Research for the Fatigue of Mild Steel by Etching. H. Yamanouchi and T. Inukai. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 63–64). [In English]. Photomicrographs show the development of slip bands, fatigue cracks, and failure with increasing stress cycles.—K. E. J.

Influence of Testing Frequency on the Fatigue Strength of Steels and Light Alloys. T. Wyss. (*Amer. Soc. Test. Mat. Bull.*, 1953, Feb., 31–34). The fatigue strength for 1,000,000 cycles has been determined for different grades of carbon and alloy steels at 350 and 10,500 cycles/min. and for various light alloys at 350 and 8000 cycles/min. In general, fatigue strength at higher frequencies was found only slightly greater than at low frequencies. A description of the equipment used is given, and its influence on the results obtained is discussed.

Observations Concerning the Problem of Hardness. H. Tertsch. (*Radex Rundschau*, 1950, No. 3, May, 148–152). The concept of hardness is shown to be ill-defined and correlation between various methods of measuring hardness is claimed to be difficult because of the complexity of phenomena involved. The respective effects of the orientation of crystals, crystal hardness, and structural hardness are discussed.—E. C.

Hardness and Work-Hardenability of Metals and Alloys. G. P. Chatterjee. (*Trans. Indian Inst. Met.*, 1951, **5**, 245–259). The author discusses in detail the theory of indentation hardness testing, especially the Brinell test.—D. H.

Hardness and the "Plunger" Yield Strength. H. Hanemann. (*Jernkontorets Ann.*, 1953, **137**, 1, 27–33). [In Swedish]. The author has determined hardness as the lowest specific pressure at which permanent deformation occurs in metals; this avoids inaccuracies due to the cold working of Brinell test samples. Equipment consists of a plunger or piston having a plane bearing surface 0·5 mm. in dia. mounted in a solid steel guide. Piston movement can be determined with an accuracy of 5 μ. Tables showed that the relationship between yield strength and Brinell hardness for lead, copper, zinc, iron, and four Cd–Hg alloys was non-linear. The yield strength varied directly with scratch hardness.—G. G. K.

Anisotropy Phenomena Occurring During Vickers Microhardness Tests. H. Tertsch. (*Radex Rundschau*, 1950, No. 4, Aug., 194–201). The complex problems of hardness testing are outlined. Microhardness tests on calcite are discussed in detail to elucidate anisotropic behaviour of crystals. The effects of such anisotropy on practical hardness tests are considered.—E. C.

Strain Ageing in Iron and Steel. J. D. Fast. (*Philips Tech. Rev.*, 1952, **14**, Aug., 60–67). Ageing phenomena are ascribed to impurities such as carbon and nitrogen. It is shown that the explanation of the phenomena by the dislocation theory meets the difficulty that in the state of equilibrium the amounts of dissolved carbon and nitrogen are too small to cause the effects observed. It is therefore concluded that carbon and nitrogen pass into solution from precipitated particles of carbide and nitride, and then flow towards the dislocations. Experiments on pure iron alloyed with carbon and nitrogen indicate that the latter has a much greater effect upon the ageing properties of iron than carbon. Manganese does not affect the behaviour of nitrogen in strain ageing, although it has a marked effect on quenching ageing. (10 references).—P. M. C.

The Effect of Cold Working on Precipitation Hardening and Superimposed Structure. A. Kussmann. (*Metall*, 1953, **7**, Mar., 182–186). The connection between cold working and precipitation hardening is discussed on the hypothesis that this is the result of local high temperature. Many observed phenomena support this, but there remain the two objections: (1) Smallness of regions of high temperature, and (2) the time factor.—J. G. W.

On Wear Properties of Spheroidal Graphite Cast Iron. F. Hayama. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 20–22). [In English]. Wear resistance of several types of cast iron was tested using a rotating drum rubbing apparatus. All types of spheroidal graphite cast iron do not exhibit good wear properties, particularly the 'bull's-eye' type, suitable for constructional use. The high-hardness pearlitic type shows wear resistance, and the structure which exposes bands of cementite in steadite exhibits wear resistance over a limited range of conditions.—K. E. J.

Friction Between Solid Bodies. R. Schnurmann. (*Manchester Assoc. Eng.*, Mar. 27, 1953, Advance Copy). A review is given of a number of published papers concerned with the friction between solid bodies.—B. G. B.

The Influence of Wear-Product in Accelerating Wear. M. S. Mitra and L. R. Vaidyanath. (*Trans. Indian Inst. Met.*, 1951, **5**, 295–309). A review is given of the different theories on the fundamental aspects of friction and related wear. Types of wear are classified. Experiments are described emphasizing the role played by the wear product in accelerating wear. The following conclusions are arrived at from tests: (1) The presence of the wear-product accelerates the rate of wear. (2) Wear loss is reduced by 95% by dry removal of wear products. (3) Wear rate and initial time of running-in are reduced. (4) Frictional torque and work done are reduced by increase in speed under similar working conditions. (5) Wear loss is proportional to work done. (6) Dynamic friction is less than static friction and when wear products are removed there is a tendency for the frictional torque to drop gradually.—D. H.

Increase of High Magnetostriction by Magnetic Anneal. H. E. Stauss and G. Sandoz. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1342–1343). The authors show that an appreciable increase in linear magnetostriction can be produced by a 'magnetic anneal' of 87%-Fe–13%-Al and 69%-Co–31%-Fe alloys, which normally have high magnetostriction values. The theory of this effect is discussed.—G. F.

Three Years' Experience with a New Micro-Abrasion Tester. P. Grodzinski. (*Research*, 1953, **6**, Mar., 98–105). A new wear tester, which gives promising results, uses small loads, very high peripheral speeds and short test periods. Because of its small size, it can be used to take many readings on a small area, and it can be applied directionally. Results of tests on specific materials, and correlations with other methods, are given. (17 references).—K. E. J.

Domains of Reverse Magnetization. L. F. Bates and D. H. Martin. (*Proc. Phys. Soc.*, 1953, A, **66**, Feb. 1, 162–166). A study was made by the powder deposit technique of domains of reverse magnetization arising when an initially saturated silicon-iron crystal is demagnetized. In one case

an artificial defect was introduced. Imperfections in the surface are very important in determining the observed phenomena, and the crystal surfaces may act as imperfections.

Electrical Behaviour of Thin Metal Layers. A. Schulze and H. Eicke. (*Metall*, 1953, **7**, Feb., 106–109; Mar., 171–181). The authors investigated the electrical properties of layers of gold, platinum, rhodium, silver, copper, iron, nickel, antimony, and manganin. They found that the logarithm of the steady resistance in air varied linearly with film thickness. The temperature coefficient varied inversely with the absolute value of resistance, but never exceeded one part in a thousand.

Ultrasonics in Solids. G. Bradfield. (*Research*, 1953, **6**, Feb., 68–79). Some properties of solids are described, particularly thermal vibration, specific heat, elasticity, and the effects of lattice imperfections. Ultrasonic methods are applicable to measuring elastic properties and grain size, checking high-accuracy clocks, flaw detection, delay lines, cutting hard metals, grain refinement, and some therapeutical treatments. Methods of generation are described. (43 references).

Some Metallurgical Applications of Ultrasonics. A. E. Crawford. (*Metallurgia*, 1953, **47**, Mar., 109–113). The factors governing the design of ultrasonic generators for metallurgical applications are discussed. Magnetostriction transducers are robust and can be connected to coupling rods by soft or hard soldering; they also have advantages over other types when it is necessary to propagate the sound waves into materials at elevated temperatures. Several applications of ultrasonics are described, including grain refinement, degassing, and metallic coatings.—B. G. B.

Experience with the Non-Destructive Testing of Materials with Ultrasonic Waves. W. Felix. (*Radex Rundschau*, 1951, No. 5, Sept., 167–177). The principle and methods of non-destructive testing with ultrasonics are reviewed and a number of experimental and practical tests using British equipment are described. Specialized applications, including the examination of welds are dealt with.—E. C.

Testing of Welded Rails by the Ultrasonic Method. W. Lehfeldt. (*Schweissen u. Schneiden*, 1953, **5**, Mar., 110–112). A brief description is given of the ultrasonic method of testing as applied to welded rails.—U. E.

Ultrasonic Testing of Parts While Immersed in Water. W. C. Hitt. (*Machinery*, 1953, **82**, Feb. 6, 250–251). Non-destructive ultrasonic testing of steel and aluminium aircraft components, while immersed in water, is now carried out at the Santa Monica Division of the Douglas Aircraft Co., Santa Monica, Calif., U.S.A. The method is described.—E. C. S.

Reliability of Test and Inspectors. (*Machinist*, 1953, **97**, Apr. 11, 586). In evaluating non-destructive test methods, it is important to discriminate between the reliability of the test method and the judgment of the inspector. The A.S.T.M. has produced standards for film photography which grade defects into five classes so that the customer may specify what class of radiographic examination is permissible.—R. A. R.

A Metals Comparator for the Inspection and Classification of Metals. B. M. Smith. (*Non-Destructive Test.*, 1952, **11**, Oct., 41–46). The General Electric Metals Comparator is described. The equipment is basically an impedance comparator, operating at test frequencies of 50 to 10,000 cycles/sec. Two coils, into which a standard material and the test material are inserted, are used to indicate differences in magnetic properties, or in resistivity in the case of non-magnetic materials. Many uses are described, including the checking of hardness, case depth, plating thickness, and the detection of internal and surface flaws.—P. M. C.

Iridium 192 in Industrial Radiography. J. V. Rigbey and C. F. Baxter. (*Non-Destructive Test.*, 1952, **11**, Oct., 34–40). A 20-Curie iridium^{192} source, with a radiation intensity of about 1700 milliroentgens/hr. at 1 m., has been used for the radiography of specimens less opaque than those for which cobalt^{60} is commonly used. When compared with X-rays it possesses the same advantages and disadvantages of other gamma sources. Exposure and decay charts are given, and safety precautions, positioning of source, scattered radiation, and latitude are discussed.—P. M. C.

Modern Techniques in High-Voltage Radiography. E. A. Burrill. (*Non-Destructive Test.*, 1952, **11**, Oct., 23–27). The author reviews the radiographic characteristics of high voltage X-rays, in order to establish the relative merits of 250 kV. and 2 million V. sources. Economic considerations, including the cost of X-ray sources from 250 kV. to 20 MeV., are also dealt with. For radiography in the 2 to 12 in. steel thickness range, the 2 MeV. Van der Graff X-ray generator is considered to be a unique source, because of its 0·02 in. focal spot.

Various Penetrameter Types and Their Limitations. N. C. Miller and G. H. Tenney. (*Non-Destructive Test.*, 1952, **11**, Oct., 28–32). The use of penetrameters is an accepted method for determining the resolution or sensitivity of the radiographic inspection procedure. Experiments are described in which three types of penetrameter were examined: (1) A conventional type, *i.e.*, a thin steel plate with a cylindrical hole, the ball type, and the wire type. Three types of artificial cavities were also examined: Spherical holes, and drilled holes with their axes parallel to and perpendicular to the face of the slab. Various energies of radiation were used. It was concluded that no single penetrameter can represent all types of cavity, and the conventional penetrameter was considered to be the all-round type.—P. M. C.

Industrial Fluoroscopy. D. T. O'Connor. (*Non-Destructive Test.*, 1952, **11**, Oct., 11–22). The author describes many applications of fluoroscopy in the field of non-destructive testing and inspection. The limitations of the method imposed by materials, screens, and human eye at low brightness levels are discussed. (30 references).—P. M. C.

The Techniques, Applications and Scope of Non-Destructive Testing in Industry. J. D. Hislop. (*North-East Coast Inst. Eng. and Shipbuilders, Advance Copy*, 1953, 225–244). The main methods of non-destructive testing (radiography, magnetic crack detection, and ultrasonics) are described, and consideration is given to their scope and limitations. The ways in which they can serve the engineer by providing information on soundness and serviceability, and the parts played by the various personnel concerned, are discussed. The economics of testing are considered both from the point of view of the cost of their application, and of the savings made by their use.—P. C. P.

Strong Heat Resistant Alloys and Metallic Combinations. A. Michel. (*Metal Progress*, 1953, **63**, Jan., 120–124). The properties and uses of ferritic and austenitic steels and alloys are considered and future developments are discussed. The future evolution of ceramic and cermets for use at high temperatures is also considered.—B. G. B.

Gas—Dangerous Enemy of Steel. J. Trapl. (*Hutník*, (Prague), 1953, **3**, 1, 8–9). [In Czech]. A survey is given of the major effect of gases, particularly nitrogen, oxygen, and hydrogen on the properties of steel. Methods for minimizing their content in steel are outlined.—P. F.

Effect of Titanium in Steel. P. Mehta. (*Trans. Indian Inst. Met.*, 1951, **5**, 111–140). The influence of up to 0·6% titanium on the structure and properties of medium-carbon manganese and low-carbon nitrogen steel is discussed. Titanium in amounts greater than 0·1% eliminates the coarse dendritic pattern common to aluminium-killed steels. Titanium in amounts as low as 0·072% eliminates blowholes and centre porosity in ingots. Its effect on the constitution of medium-carbon manganese–titanium steels was investigated by dilatometric measurements. The A_3 critical points rise with titanium content. Titanium increases hardenability. The effect of this element on the strain-ageing of low-carbon nitrogen steels was also studied.—D. H.

How to Save Alloying Elements. K. Motlík. (*Hutník*, (Prague), 1953, **3**, 1, 5–7). [In Czech]. The question of replacing certain alloying elements in steels, particularly molybdenum, by other elements and by heat-treatments is discussed. Alloying elements can be saved by: (*a*) Careful separation of the scrap containing them from other scrap; (*b*) selecting the most appropriate type of steel from the point of view of its intended application, particular regard being paid to hardenability; (*c*) substituting wherever possible low-alloy steels which are easily heat-treated for high-alloy steels; (*d*) the application of quench-hardening, and (*e*) the wider use of metallizing and plating. Further research to improve Mn–Si steels is required.—P. F.

Effect of Composition on the Warm-Working Characteristics of Austenitic Alloys. G. T. Harris and H. C. Child. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 325–330). [This issue].

The Influence of Boron on the Properties of Blackheart Malleable Cast Iron. G. Martin. (*Fonderie*, 1953, Jan., 3265–3280). Experimental castings containing up to 0·03% boron were prepared and annealed by heating to 930° C. and holding for varying times to decompose free cementite, then cooled to 740° C. and held at that temperature to decompose pearlite. Boron up to 0·008% did not affect

the time required to decompose cementite, but with higher percentages, longer holding times were required. Increasing boron content reduced the time needed to decompose pearlite. Tensile strength, elastic limit, and elongation decreased with increasing boron content.—J. MCK.

Mechanical Properties of Alloy Steels in Investment Castings. S. C. Churchill. (*Engineering*, 1953, **175**, Feb. 6, 164–167). Investment castings, although cooled in and with the moulding flask to room temperature, were not found to be in the annealed state. The effect of different heat-treatments on the mechanical properties and microstructure of low-alloy investment-cast Ni–Cr–Mo steel was studied and heat-treatments were developed to give satisfactory tensile properties.—J. MCK.

The Properties of Steel Wire. W. E. Wagenknecht. (*Wire Prod.*, 1953, **2**, Feb., 19). The author reports that in the production of rope wires, a pre-anneal at 700° C. gives a slight improvement in all test values. A decarburizing anneal at 1000° C. causes the tensile strength and fatigue limit to decrease and leads to a marked improvement in the torsion test results.—J. G. W.

Influence of Pre- and Post-Treatment on the Properties of Welded Basic-Bessemer and Open-Hearth Steel. W. Püngel. (*Schweissen u. Schneiden*, 1953, **5**, Feb., 62–66). The metallurgical properties of welded Bessemer and open-hearth steels and the effect of cold rolling before welding were studied.

Contribution to the Study of "Rollodur" Steel for Tools of High Cutting Capacity. A. Collaud. (*Roll'schen Eisenwerke Mitt.*, 1952, **11**, July–Dec., 73–91). So far all attempts to substitute steels of high chromium content for 18/4/7 W–Cr–V steel have failed. The author claims that the stabilization of austenite under the influence of chromium is far from disadvantageous. A heat-treatment (differing entirely from that for 18/4/1 steel) and the selection of alloying elements such as tungsten, molybdenum, and vanadium, permit the production of steels for very high cutting speeds. With the correct composition and heat-treatment the objections usually made against chromium steels with regard to retention of hardness of the martensite and to hot hardness appear to be unfounded.—E. C. S.

The Use of Special Steels at Whyalla and Iron Knob. H. C. Wilkinson. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 137–147). Austenitic manganese steel is used for parts of an electric shovel, crusher jaw liners, grizzly bars, railway crossing frogs, and the impact sections of chutes. Vibrac type steels are used for boom shipper shaft rack pinions of the electric shovels, heavy bevel gears, caterpillar intermediate rollers, spanners, and truck axles. Nyval steel is also mentioned for locomotive air-compressor piston rods, shovel boom shipper shafts and all welded dipper sticks. Correct handling, heat-treatment, and stocking of the separate steels is emphasized.—J. C. B.

Corrosion and Heat Resisting Steels for the Mining Industry. H. R. Dalziel. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 91–119). After a general differentiation between stainless irons and steels, and heat-resisting steels, the author deals with each type in detail giving numerous examples to illustrate his points. Corrosion is discussed generally, and followed by a consideration of contact corrosion, stress corrosion cracking, pitting, and inter-crystalline corrosion, and the galvanic effects caused by the position of the alloys in the galvanic series in sea water. Steels for service at high temperatures must also possess the strength necessary to support a useful load when heated to the working temperature.

Paper-Thin Metals—Availability Stimulates Design. M. Sherman. (*Product Eng.*, 1953, **24**, Jan., 138–141). With the development of the Sendzimir mill a wide variety of metal strip can now be rolled to thicknesses down to 0·0005 in. and to tolerances as close as ± 0·0001 in. The major uses for very thin metal strips are in the instrumentation, electronics, and aircraft industries; pressure vessel bursting discs, diaphragms, and magnetic cores are typical examples. There is also a growing demand for microshims to save high tolerance machining.—A. M. F.

Damping of String Vibration Due to the Internal Friction. T. Nishihara and H. Miki. (*Kyoto Univ., Eng. Res. Inst., Tech. Rep.*, 1952, **2**, Mar., 61–74). [In English]. Damping of vibration in a wire is deduced from a previous theory of internal friction, and compared with deductions from thermo-elastic theory. The logarithmic decrement should be approximately independent of tension and amplitude of vibration. These results were confirmed experimentally.—K. E. J.

New Stainless Stretches Nickel. A. G. Gray. (*Steel*, 1953, **132**, Mar. 9, 94–97). This article describes the use of TRC stainless steel (Cr 15·0% min., C 0·1% max., Ni 1·0% max., Mn 16·5%, N_2 0·15%). This replaced a 7% Ni steel for railway carriage structures.—D. L. C. P.

New Gray Cast Iron with Eutectic Graphite Structure—"S–H Cast Iron"—and Its Mechanical Properties. H. Sawamura. (*Mem. Fac. Eng. Kyoto Univ.*, 1952, **14**, Mar., 77–82). [In English]. Experimental iron castings with a eutectic graphite structure have been made by treating the melt with slags containing > 9% of TiO_2. Titanium content of the metal is 0·2% or more. Some mechanical properties are given. The tensile strength is almost independent of the carbon content (25–27 kg./sq. mm.).—K. E. J.

On Austenitic Malleable Cast Iron (Report 1). N. Tsutsumi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 42–45). [In English]. Austenitic black-heart malleable cast irons were obtained by single-stage annealing for 40–60 hr. at 950° C. Compositions were 2–3% C, 1·5–2·0% Si, 8–13% Mn, 0·15% P, and 3–5% Cu or Ni. Tensile strengths were in the range 40–50 kg./sq. mm., and hardnesses 9–22 Rc. Reducing or carburizing atmospheres were necessary. The high manganese content may affect mechanical properties, particularly ductility, adversely.—K. E. J.

Contribution to the Study of the Toughness of Grey Cast Irons. A. Collaud. (*Roll'schen Eisenwerke Mitt.*, 1952, **11**, July–Dec., 93–104). All grey cast irons present intergranular fractures which are characteristic of brittle rupture without perceptible deformation. Accordingly tests on notched bars are superfluous in the case of grey cast irons. Tests in which the influence of a blow on a bar which was *not* notched were carried out. These demonstrated that toughness as well as static strength depend equally upon graphite content and physical properties of the matrix. Various grey cast irons can behave quite differently, according to whether they are subjected to a static or dynamic strain, especially if they have previously been heat-treated. In certain cases of equal static strength, impact tests have shown toughness values which differed by 100% from each other. It is wrong to consider grey cast irons as specifically brittle metals.—E. C. S.

Cast Iron as a Constructional Material. E. Piwowarsky. (*Jernindustri*, 1953, **34**, 1, 8–15). [In Norwegian]. Cast iron is increasing in importance as a material. This is due to: (1) Constant increases in tensile strength from 10 kg./sq. mm. in 1860 to 43 kg./sq. mm. today, lighter construction, and the amendment of the old classic plastic design theory. Of great importance has been the discovery of ductile cast iron. American calculations show that welded constructions are 200–350% dearer than cast iron, whilst high-class castings are superior to steel and bronze gear wheels.—G. G. K.

Nodular Iron Tackles Big Jobs. T. E. Eagan. (*Steel*, 1953, **132**, Mar. 16, 102–104). Ductile cast iron in which most of the graphite is in spheroidal form is suitable for many applications; the physical properties are set out. Problems in its manufacture are being overcome. Its castability, yield point, and reactance to wear and shock make it an attractive material for large and small engine parts, and it is suitable for furnace doors, ingot moulds, and other temperature applications because of its resistance to growth and scaling.

METALLOGRAPHY

Metallography—New Instrumentation and Techniques. A. B. Kinzel. (*Metal Progress*, 1953, **63**, Jan., 78–83). A number of recent advances in this field are reviewed. Among the subjects discussed are the use of phase contrast microscopy for the examination of polished specimens, the development of the reflecting microscope for use with a heated specimen, the ultra-violet microscope, the electron microscope, and improvements in polishing.—B. G. B.

Surface Decarburization of Steels. M. Sýkora. (*Hutník*, (Prague), 1953, **3**, 2, 34–35). [In Czech]. Methods, mainly micrographical, for determining the degree of decarburization, are discussed.—P. F.

Ferrite in Austenitic Steels Estimated Accurately. T. V. Simpkinson. (*Iron Age*, 1952, **170**, Dec. 11, 166–169). The effects of size, shape, and orientation of the ferrite particles on the calibration of the Amnico-Brenner Magne-Gauge are

considered. This gauge is used for determining the percentage of ferrite in mainly austenitic stainless steels, and calibration curves are developed which simplify this estimation.—A. M. F.

Making Laboratory Electric Furnaces. L. R. Barrett. (*Research*, 1953, **6**, Feb., 61–67). Electric furnaces are most suitable for operations to be carried out at elevated and carefully controlled temperatures. Principles of design and construction are given for general-purpose furnaces to be used at temperatures up to 1200° C. and up to 1800° C.—K. E. J.

Inelastic Neutron Scattering in Iron. B. Rose and J. M. Freeman. (*Proc. Phys. Soc.*, 1953, **66A**, Jan. 1, 120–121). Preliminary results for iron are given, using a method of measuring the excitation function of inelastic neutron scattering by studying the γ radiation from the excited states produced.—K. E. J.

Crystal Structure and Antiferromagnetism in Haematite. B. T. M. Willis and H. P. Rooksby. (*Proc. Phys. Soc.*, 1952, B, **65**, Dec. 1, 950–954). X-ray analysis was made of the crystal structure of hematite in the range 20–950° C. on cooling through approx. 675° C. the rhombohedral unit cell suddenly expands in the triad axis direction. This is interpreted by antiferromagnetism, with a Curie point at approx. 675° C. The behaviour is analogous with that of the cubic oxides FeO and Fe_3O_4. (11 references).—K. E. J.

The Mechanics of Metal Crystals. E. N. da C. Andrade. (*Proc. Roy. Inst.*, 1951, **35**, 237–251). The author reviews in detail the connection between the crystalline structure of metals and alloys and their physical properties.—B. G. B.

The Phenomenological Method in Rheology. A. Graham. (*Research*, 1953, **6**, Mar., 92–97). Principles which have to be considered in building up the fundamental science of rheology are discussed. The use of mechanical models for guidance, and some accepted physical principles cannot be relied upon to lead to an adequate mathematical theory. A progressive method of evolving theory by direct reference to experiment is described, and is shown to lead to the differential 'rheological equation of state.'—K. E. J.

Dislocations and the Theory of Solids. N. F. Mott. (*Nature*, 1953, **171**, Feb. 7, 234–237). The properties of dislocations and the strong evidence for their existence in annealed materials are discussed. This concept explains some of the most important facts about plastic flow of crystalline solids.

Effect of a Prequench on the Martensite Reaction in Tool Steel. J. J. Gilman. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**; *J. Met.*, 1952, **4**, Dec., 1300–1301). The author has investigated the formation of martensite from austenite formed from an annealed structure and from austenite formed from tempered martensite, using a manganese non-deforming tool steel and carrying out quenching tests with some of the specimens prequenched and reheated. It is shown that the pre-quenching treatment suppresses the martensite reaction.—G. F.

Modifications of an X-Ray Method for The Measurement of Retained Austenite Concentrations in Hardened Steels. K. E. Beu. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1327–1328). The author has studied the various phases of the integrated intensity X-ray method of measuring retained austenite concentrations, and proposes several modifications which reduce the time required for a determination and increase the possible accuracy of the method.—G. F.

An X-Ray Diffraction Study of the Transformation of Retained Austenite by Fracture. L. W. Pateman and H. S. Peiser. (*Nature*, 1953, **171**, Apr. 18, 696–697). A glancing X-ray diffraction technique revealed retained austenite in a 1·5%-Cr steel, but none could be detected on a surface of fracture. Transformation here is presumably due to highly localized shear deformations at the position of fracture. The result indicates that freshly broken surfaces may show structures not typical of the metal in bulk.—A. G.

Transformations in Steels—Isothermal and During Continuous Cooling. G. P. Contractor and V. G. Paranjpe. (*Trans. Indian Inst. Met.*, 1951, **5**, 141–145). The method of correlating isothermal and continuous cooling transformations in steels is outlined. While qualitative results can be deduced by this method, it does not give good quantitative agreement in all steels. Factors which may be responsible for this are mentioned.—D. H.

Bainite Reaction in Steels. V. G. Paranjpe and D. D. Kaushal. (*Trans. Indian Inst. Met.*, 1951, **5**, 147–172). A critical review of existing knowledge of the bainite reaction is presented and attention is drawn to some aspects not well understood. After describing the temperature range, kinetics, structure, and crystallography of bainite, the effects of carbon and alloying elements on the bainite reaction are discussed.

Research on Rapid Heating of Steels (Report II). K. Yokota and N. Iguchi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 56–58). [In English]. Dilatometric analysis shows that the $\alpha \rightarrow \gamma$ transformation in carbon steel proceeds by pearlitic grains transforming to eutectoid austenite, which grows at the expense of the ferritic matrix. The transformation interval is more affected by heating rate with low carbon steel. Transformation is accelerated by diffusion of carbon atoms. The temperature of transformation is greatly affected by heating rates and atomic diffusion velocity.—K. E. J.

Some Corrections to Cast Iron Diagrams of Maurer and Others. I. Iitaka. (*Waseda Univ., Rep. Casting Res. Lab.*, 1952, No. 3, 1–2). [In English]. Modifications are suggested for diagrams indicating the influences of the silicon and carbon contents, and the cooling rate on the structures of cast irons. They concern particularly the boundaries between cast iron and cast steel, and between hypo- and hyper-eutectic irons.—K. E. J.

Equilibrium Relations in the Iron–Nitrogen System. V. G. Paranjpe and M. Cohen. (*Trans. Indian Inst. Met.*, 1951, **5**, 173–186). The existing data on the thermodynamics of iron–nitrogen phases are combined with the results of a recent determination of the iron–nitrogen phase diagram to compute the effect of pressure on this system. Several iso-instability and isothermal sections through the temperature-instability concentration diagram of this system are presented. Some comments are made on the solubility of nitrogen in the α-phase.—D. H.

Liquidus Surface of the Fe–S–O System. D. C. Hilty and W. Crafts. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1307–1312). The authors have derived experimentally the liquidus diagram for the Fe–FeS–FeO region of the Fe–S–O system. A ternary eutectic is located at 67% Fe, 24% S, 9% O, and about 920° C. A liquid miscibility gap extends from the Fe–O side to 21·5% S, with a minimum at about 81·5% Fe, 16·5% S, 2% O, and 1345° C. The authors have also determined the solubility of oxygen at several temperatures in liquid iron containing sulphur. With increasing sulphur, the oxygen solubility first decreases slightly up to about 0·10% S, and then increases rapidly.

An Investigation of Equilibrium Diagram of Fe–As–C System. H. Sawamura and T. Mori. (*Mem. Fac. Eng. Kyoto Univ.*, 1952, **14**, July, 129–144). [In English]. As part of research on the influence of arsenic on steel, the Fe–As and Fe–As–C diagrams were obtained for the ranges 0–40·16% As and 0–6·67% C. Nearly 200 specimens were made up, and thermal analysis, dilatometry, and microscopical examination were used. The Fe–As–C equilibrium diagram was produced from eleven sections of the ternary system (eleven invariant points).—K. E. J.

CORROSION

Polarization and Passivity in Metallic Corrosion. W. Katz. (*Metall*, 1953, **7**, Mar., 161–170). The author reviews the application of potential and polarization measurements to the study of the corrosion of metals on the basis of as yet unpublished researches at the Berlin Materialprüfungsamt and of the observations of other investigators. He discusses the potential/current-density curves for, *inter alia*, silver, cadmium, zinc, iron, aluminium, and copper, and shows how changes in potential may be used to follow the formation of protective layers as, for example, when iron or zinc is immersed in phosphate solutions. He also refers to passivity phenomena on lead, iron, and titanium.—J. C. H.

Studies of the Behaviour of Metals of the Iron Group in Electrolytes. G. Kröncke and G. Masing. (*Werkstoffe u. Korrosion*, 1953, **4**, Mar., 86–95). The polarization of cobalt, nickel, and iron in certain solutions has been studied and attempts are made to explain the hysteresis phenomena observed for cobalt and iron by reference to surface oxide films. No difference in potential was noted between the cubic and hexagonal forms of cobalt. Cold-worked steel had a more anodic potential than non-deformed steel, but polarized more readily.—J. C. H.

Basic Factors in Electrolytic Corrosion. E. F. Wolf. (*Iron Steel Eng.*, 1953, **30**, Jan., 102–105). This paper reviews briefly the fundamental principles of electrolytic or electro-

chemical corrosion and discusses factors influencing speed of corrosion, as well as corrosion prevention, particularly cathodic protection.—M. D. J. B.

The Condensation of Water, Derived from the Natural Moisture Content of the Wrapping Paper, on to Packed Steel. G. Schikorr. (*Werkstoffe u. Korrosion*, 1953, **4**, Mar., 81–86). An investigation of the corrosion of steel by packing paper is reported. The equilibrium water contents of paper in contact with air of known relative humidities were determined both in absorption and desorption experiments; there was a slight hysteresis effect. For the paper tested, this moisture content varied from 6% in air of 57% relative humidity to 18% in air of 98% relative humidity. These quantities are of a much greater order of magnitude than is needed to saturate the enclosed packing space. So if the external temperature rises, the moisture evolved from the paper condenses on the cold steel. The remedy is to store the paper under dry conditions, preferably below 66% relative humidity.

Screening Stainless Steels from the 240 Hr. Nitric Acid Test by Electrolytic Etching in Oxalic Acid. M. A. Streicher. (*Amer. Soc. Test. Mat. Bull.*, 1953, Feb., 35–38). A new method is described whereby certain stainless steels may be evaluated for susceptibility to intergranular corrosion in about 15 min.; it is based on the type of microstructure revealed by electrolytic etching in oxalic acid. If the steels show appreciable intergranular attack in this etch, they are subsequently tested in nitric acid to ascertain whether their degree of intergranular susceptibility is within that allowed by the maximum permissible nitric acid rate for the given steel.—B. G. B.

On Acid-Resisting Silicon Steel. I. Iitaka and K. Sekiguchi. (*Waseda Univ., Rep. Casting Res. Lab.*, 1951, No. 2, 5–6). [In English]. Silicon steel (5·5% Si) has greater resistance to HCl attack than carbon steel. With additions of 2 or 5% copper its resistance to HCl is high (equal to that of 18/8 stainless steel), although resistance to other acids is low. Addition of nickel further improves resistance to HCl, by increasing the solid solubility of copper. Additions of chromium to silicon steel improve resistance to sulphuric, nitric, and acetic acids.—K. E. J.

Control of Internal Corrosion of Tankers. Part I—The Nature of Corrosion and Its Control. W. B. Jupp. (*Motor Ship*, 1953, **33**, Jan., 443–444). Two tankers operating on the West Coast of America were carefully examined for the increase in corrosion over 15 years. A classification of the times of corrosive attack was made on the basis of the type of oil cargo, and whether the ship was loaded, in ballast, empty or clean. Suggestions are made to reduce the corrosion, and are divided into the mechanical and electrochemical approaches.—J. C. B.

Control of Internal Corrosion of Tankers. Part II—Inhibitors in Cargo. J. Malcolmson, W. Quimby, G. Pingrey, and J. Oosterhout. (*Motor Ship*, 1953, **33**, Jan., 444). Laboratory trials and tests conducted to reduce corrosion are briefly described, followed by the results of applying Santolene C on a ship sailing between the Gulf of Mexico and Atlantic coast ports.—J. C. B.

Control of Internal Corrosion of Tankers. Part III—Corrosion Control in Practice. A. R. Kurz. (*Motor Ship*, 1953, **33**, Mar., 528–529). Two fundamental methods for corrosion control were suggested for simultaneous application: (1) Chemical inhibition of non-ballast tanks using a special solution of an inexpensive, but effective, corrosion inhibitor; and (2) cathodic protection of ballast tanks using magnesium anodes. The tanker S.S. *Cherry Valley* was used as the test ship over a period of six years, and the results are indicated with the improvements achieved. Finally, the protection of the gas exhauster by chemical inhibition is discussed.

The Influence of Corrosion on the Cracking of Pressure Vessels. H. R. Copson. (*Welding J.*, 1953, **32**, Feb., 75s–91s). This is a review of literature on stress corrosion cracking of pressure vessels and corrosion fatigue. (101 references).—U. E.

Improved Method of Testing Steels for Susceptibility to Stress Corrosion Cracking. W. Rädeker. (*Stahl u. Eisen*, 1953, **73**, Apr. 9, 485–490). The susceptibility of structural steels to stress corrosion cracking has been determined by subjecting tensile test specimens to a constant stress, less than the ultimate tensile strength, while immersed in a calcium-nitrate/ammonium-nitrate solution and noting the life, *i.e.*, time to fracture. The life increases with decreasing stress but the relationship between log(stress) and log(life) is not quite linear; there is a marked change of slope in the vicinity of the elastic limit. Cracking occurs even when the specimens are stressed below their elastic limit. The life increases with decreasing concentration of the corroding solution, the relationship between log(life) and log(concentration) being linear, and with decreasing solution temperature. The susceptibility to stress corrosion cracking can be affected to some extent by heat-treatment. The method described is suitable for testing welds and the mean rate of crack propagation can be calculated from the results.—J. P.

Corrosion. M. G. Fontana. (*Indust. Eng. Chem.*, 1952, **44**, Dec., 83A—86A). Most corrosion problems may be solved by several methods or combinations normally decided by economic considerations. Advantages, with examples, are discussed for the following methods: Improving resistance by alloying, cathodic protection, thin metallic or inorganic coatings, organic coatings, use of purer metals, alteration of environment, use of non-metallic constructional materials, and improvements in design.—K. E. J.

ANALYSIS

Recent Developments in Metallurgical Analysis. I—Electrochemical Analysis. II—Titrimetric Analysis. III—Gravimetric Analysis. T. S. West. (*Metallurgia*, 1952, **46**, Dec., 313–316; 1953, **47**, Jan., 45–51; Feb., 97–106). Recent advances in electrochemical analytical methods are reviewed. The determination of copper, silver, cadmium, selenium, tellurium, thalium, lead, bismuth, antimony, and tin by electrochemical methods are described. In Part II a few of the many new reagents and important modifications to existing titrimetric methods are reviewed. Among the new titrants mentioned are quinquivalent molybdenum and mercurous nitrate. Recent work on stannous, titanous and chromous chlorides is discussed and the application of complex ions in titrimetry is reviewed. (81 references). In Part III several new precipitants for use in gravimetric analysis and the techniques employed in their use are described. (77 references).—B. G. B.

The Practice of Polarography. J. A. Lewis. (*Indust. Chem.*, 1953, **29**, Mar., 125–127). The choice of suitable supporting electrolytes is discussed and a list of those found satisfactory for many elements, and approximate half-wave potentials are given. Some practical hints in polarographic techniques are mentioned.—T. E. D.

A Single Detector Split-Beam Automatic Recording Spectrophotometer. H. W. Etzel. (*J. Optical Society of America*, 1953, **43**, Feb., 87–90).

Instrumental Method of Analysis. A. B. Hollebon and J. F. Finlayson. (*Proc. Australasian Inst. Min. Met.*, 1951, Sept.–Dec., 121–136). A critical review of the advantages and disadvantages of the use of instruments in inorganic analysis is given, with special reference to spectrographs (emission and absorption), and polarographs.—J. C. B.

Determination of Oxygen in Iron in the Presence of Sulphur by the Vacuum-Fusion Method. H. L. Hamner and R. M. Fowler. (*Trans. Amer. Inst. Min. Met. Eng.*, **194**: *J. Met.*, 1952, **4**, Dec., 1313–1315). The authors show that carbon disulphide and carbonyl sulphide are present in the gases from a vacuum extraction of iron or steel containing sulphur and, when the sulphur exceeds about 0·05%, provision must be made to remove the sulphur gases during vacuum fusion analysis for oxygen or high results will be obtained. Hydrogenation to H_2S and absorption in lead acetate has proved satisfactory.—G. F.

The Determination of Copper in Iron and Steel. Methods of Analysis Committee. (*J. Iron Steel Inst.*, 1953, **174**, Aug., 335–338). [This issue].

Periodate Method for Manganese and Effect of Band Width. M. D. Cooper. (*Analy. Chem.*, 1953, **25**, Mar., 411–416). Two periodate techniques for manganese determination, the perchloric reference method and the nitrite reference method, have been studied. Precision was found to be 0·2–0·4% when using a Beckman spectrophotometer. The nitrite reference method is more rapid, but may involve a 2–3% error in the analysis of tungsten steels.—A. G.

Rapid Gas Analysis by Dynamic Method. (*Metallurgia*, 1953, **47**, Mar., 158–160). By using a dynamic method of gas analysis results which formerly took over an hour to obtain are now available in a few minutes. The apparatus used, which incorporates a number of soap film meters, is described together with its mode of operation.—B. G. B.

Spark Testing of Tool Steels. J. Lomas. (*Brit. Steelmaker*, 1953, **19**, Feb., 86–89). The spark test is a simple method of sorting tool steels of different chemical compositions which have become accidentally mixed. The author briefly describes the correct way to use this test and outlines the essential conditions.—G. F.

Automatic Recording of Carbon Dioxide by Conductometry. R. D. Goodwin. (*Analy. Chem.*, 1953, **25**, Feb., 263–265). A method is described for the determination of burning rates and total carbon content in combustion experiments in which the CO_2 evolved is continuously absorbed by a solution of barium hydroxide in a conductivity cell. Total evolution is measured conductometrically, the conductivity being recorded continuously and automatically.—A. G.

Analysis of Synthesis Gas. G. L. Barthauer, Alice Haggerty, and R. J. Friedrich. (*Analy. Chem.*, 1953, **25**, Feb., 256–259). A method has been developed, combining a variety of gravimetric combustion techniques, for the rapid and accurate analysis of hydrogen, CO, CO_2, and CH_4 in synthesis gas. Some modification is needed if inert gases are also present, but the results are better than those obtained by Orsat or mass spectrographic techniques.—A. G.

Analytical Tolerances and the Detection of Mistaken Results with Particular Reference to Coal Analysis. R. C. Tomlinson and D. A. Hall. (*Fuel*, 1953, **32**, Jan., 77–81). It is usual in coal analysis to fix tolerances, *i.e.*, limits to the difference between duplicates, so that if the tolerance is exceeded, further determinations are carried out to detect whether an error has been made. The paper suggests a method for fixing tolerances and mentions the procedure which should be followed when the limits are exceeded and further determinations have to be carried out.—B. G. B.

Industrial Chrome Ore Analysis. W. H. Hartford. (*Analy. Chem.*, 1953, **25**, Feb., 290–296). On typical ores, differences in chromic oxide and iron have been halved by attention to statistical trends and improved techniques, details of which are given. The establishment of a standard sample of metallurgical chrome ore for the steel industry is discussed together with procedures leading to increased precision in long-term co-operative analysis.—A. G.

The Analysis of Chromium Ores. (*Radex Rundschau*, 1950, No. 4, Aug., 202–203). A concise description is given of the conventional method as used at the Radenthein Works.—E. C.

The Quantitative Determination of some Minerals in Ceramic Materials by Thermal Means. R. W. Grimshaw and A. L. Roberts. (*Trans. Brit. Ceram. Soc.*, 1953, **52**, Jan., 50–67). The method of differential thermal analysis has been applied to the quantitative determination of clay minerals.—E. C. S.

The Analysis of Magnesite. (*Radex Rundschau*, 1949, No. 6, Oct., 238–239). Concise instructions are given for the analysis of magnesite, using classical methods. Emphasis is laid on the need for particular care in view of the great excess of MgO over all other constituents.—E. C.

Determination of Free Lime in Slag. H. Gotô and Y. Kakita. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, July, 394–395). [In Japanese]. It was found that free lime in several types of open-hearth slag could be estimated by McPherson and Forbrick's method for cement (extraction with ethylene glycol and titration with hydrochloric acid). Results were readily obtained in 30 min.—K. E. J.

HISTORICAL

Trevithick, Rastrick and the Hazledine Foundry, Bridgnorth. S. M. Tonkin. (*Newcomen Society. Transactions*, 1947–1948 and 1948–1949, **26**, 171–183). The activities of the Hazeldine Iron Foundry at Bridgnorth in the XVIIth century are described. J. U. Rastrick was a partner in the foundry, and equipment for some of the works of R. Trevithick was manufactured there.—B. G. B.

The Iron Industry in Ångermanland. P. Norberg. (*Blad. Berg. Vänner*, 1952, **30**, 2, 73–120; 3, 121–200; 4, 201–282). [In Swedish]. A detailed historical review of the growth of the iron industry in this Swedish province describes iron foundries which have operated at various periods and lists the leading personalities involved.—G. G. K.

BOOK NOTICES

CLARK, CLAUDE L. "*High-Temperature Alloys.*" (Pitman Metallurgical Series.) 8vo, pp. xiii + 383. Illustrated. London, 1953: Sir Isaac Pitman and Sons, Ltd. (Price 60*s.*)

Mr. Clark has been associated for twenty-five years with the study of the behaviour of metals at high temperatures. He has written many papers on the subject and is also the author of a booklet published by the Timken Roller Bearing Company, with whom he is associated, on "The High-Temperature Properties of Steels." Perhaps as a consequence of devoting so much of his own time to the study of ferrous alloys, Mr. Clark writes with less confidence and authority on alloys in which iron is not a major constituent. The reader who takes the title of this book at its face value will doubtless be disappointed, as was the present reviewer, to find that predominantly non-ferrous alloys are sketchily and inadequately dealt with. The book, therefore, to some extent lacks balance.

However, on the high-temperature properties of steels Mr. Clark's text is in many ways admirable. Testing methods for high-temperature tensile testing, creep, time to rupture, relaxation and other mechanical tests are adequately described. The properties of low-, intermediate-, and high-alloy steels are described very fully and the book contains a very useful chapter on representative service failures. Engineers, in particular, will find this volume a valuable guide to the properties to be expected from the materials at their disposal.

Workers interested in the metallurgical and physical factors governing the behaviour of metals at high temperatures will be less satisfied, and will, doubtless, also complain that the book lacks balance. The author has taken most of his examples and data from work carried out in his own laboratories, and very excellent work this is. As a consequence, however, he has tended to pay less attention to work carried out elsewhere, and it is surprising to find that such comprehensive investigations as those undertaken by Glen and others on the effect of metallurgical variations on the creep properties of steels are ignored or mentioned only in the rather inadequate bibliography at the end of the book.

The author has not considered it to be his object to expend much space in explaining the phenomena which he describes. He takes the equicohesive temperature theory, with slight modifications to explain the time dependence of fracture, as an adequate explanation for all the observed phenomena, and he regards dislocations, slip mechanisms, cell formation, boundary microflow, etc., as terminological distinctions all fitting into the same basic concept. Some readers will doubtless regard this attitude as one of over-simplification. With some statements they will disagree, as, for example, when the sigma phase is described as a "complex carbide phase."

The preface to the book states that it is its primary purpose to "summarize the present status of our knowledge about the behaviour of alloys at elevated temperatures." Because of its unbalance, the reviewer considers that this purpose has been only partly achieved, but it will still serve a very useful purpose as a compilation of data and experience which have not previously been available in collected form.—A. H. SULLY.

DARKEN, LAWRENCE S., and ROBERT W. GURRY. "*Physical Chemistry of Metals.*" With a Collection of Problems by Michael B. Bever. 8vo, pp. ix + 535. Illustrated. New York, Toronto, London, 1953: McGraw-Hill Book Company, Inc. (Price 61*s.*).

Physical chemistry today is one of the essential subjects of study for the student of metallurgy, for it supplies a basis to the science of metal-winning and to that of the metallic state itself, and it is desirable that suitable textbooks designed for this purpose should be available. In these books the general principles should be expounded with appropriate selectivity; the examples quoted should be of direct interest to the metallurgist; and the important metallurgical applications should be indicated. The book now under consideration is the first on these lines which the reviewer has seen. It is a book of distinction, both in appearance and in the presentation of the subject matter.

Although providing a suitably broad background, it deals especially with the liquid and solid states in metals, the formal principles of thermodynamics and their application to metallurgical phenomena; in the latter connection there are separate chapters on Nitrogen in Iron and Steel and on The Iron–Carbon System. There is also an introduction to the kinetics of metallurgical processes. A selection of questions on each chapter is appended. It is well to make clear that the emphasis in this book is on serious physical chemistry but with a metallurgical bias, and not on metallurgy with some physical chemistry thrown in.

The book should prove valuable for metallurgical students in whose course physical chemistry is properly featured. It should also suit any practising metallurgist who is uncertain of his physical chemistry or who wants to get to grips with the subject for the first time.—A. R. Bailey.

Hilton, Richard B. "*Technology of Engineering Materials.*" La. 8vo, pp. vii + 389. Illustrated. London, 1953: Butterworths Scientific Publications. (Price 36*s.*)

This is a well produced, well illustrated, and clearly written account of the technology of engineering *metals* (and not of other engineering materials), but without any serious reference to metallurgical principles. It covers mainly patternmaking, foundry practice, and the mechanical and thermal treatment of ferrous and non-ferrous metals and alloys. There is, in addition, a useful chapter on ferrous production, as well as a cursory and not altogether accurate survey of the production of non-ferrous metals and alloys. Finally, there is a considerable glossary of metallurgical terms.

The book will be useful to the engineer or engineering student who needs some knowledge of the production of metals and metallic components without becoming involved in the principles of engineering metallurgy.—A. R. Bailey.

Pigott, E. C. "*Ferrous Analysis. Modern Practice and Theory.*" Second edition, revised. 8vo, pp. xxvii + 690. Illustrated. London, 1953: Chapman and Hall, Ltd. (Price 84*s.*)

In this, the second and greatly enlarged edition of "The Chemical Analysis of Ferrous Alloys and Foundry Materials" first published in 1942, Mr. Pigott has produced a book which treats with comprehensive thoroughness the various techniques now employed in the analysis of iron and steel. Ferro-alloys, ores, and other foundry materials are less thoroughly treated, and in some instances the value of the book might have been improved if these had been dealt with more completely. For example, iron ores receive only two pages, and the important subject of sampling ores is not treated at all.

The book is divided into five sections. The first, "Analytical Procedures," surveys the different techniques now available for ferrous analysis and considers the choice of the most suitable technique for any particular job; it also contains a valuable account of the development of photoelectric absorptiometry and of spectrographic procedure, and deals in more or less detail with such less commonly used procedures as polarography, vacuum fusion, chromatography, oscilloscopic polarography, mass spectrometry, spark testing, magnetic permeability measurements, and electron microscopy.

In the second section, entitled "The Constituents of Iron and Steel" (485 pages), thirty-one elements are considered, each under the following heads: Physical properties; extraction; ferrous properties; chemical properties; detection; consideration of methods; determination; theory of methods and bibliography. The reviewer would venture the opinion that the considerations of chemical properties and the theory of the methods might profitably have been somewhat shortened, and of the metallurgical effects of the elements (ferrous properties) even more so, as they sometimes seem to digress from the principal theme. In this way the price, which, even by present-day standards, is very high, might have been brought more within the reach of students of metallurgical analysis for whom such a book is an invaluable asset. Further, wherever possible, ionic equations should have been employed; they are not only less cumbrous than the conventional molecular type, but also are more accurate representations of the actual reaction mechanisms.

The remaining three sections deal with micro-chemical methods, alloys and ores, and refractory materials, respectively. The section on micro-chemical methods breaks new ground and, after a consideration of micro-analytical technique, methods are described for the determination of carbon, sulphur, manganese, nickel, phosphorus, chromium, and molybdenum, and also heterogeneity testing, a subject to which Mr. Pigott has given particular attention. The section on ferro-alloys, which follows, might usefully have been enlarged by the inclusion of a number of further determinations, for instance, the estimation of aluminium in ferrosilicon, which is nowadays often required, and the rapid and elegant phosphoric acid method for chromium in ferrochromium.

It is regrettable that very little consideration is given to the problem of sampling ferrous alloys. Quite a lot of work has been done on this subject lately and the importance of obtaining a representative sample before attempting to carry out an analysis is being more and more realized.

Despite these criticisms, however, Mr. Pigott is to be congratulated on having written a most useful and comprehensive work of great value. Those engaged in research into new methods will find the extensive bibliography covering the literature for the last twenty years, and listing over one thousand papers, a most valuable asset.—W. E. Clarke.

Platon, J.-G. "*Conduite du Haut-Furneau. Principes et Règles.*" 8vo, pp. 54. Paris, Liege, 1953: Librairie Polytechnique Ch. Beranger. (Price 420 fr.)

This book is an exposition of the author's admittedly unorthodox views on blast-furnace operation and their application. The minor role assigned by him to indirect reduction appears to neglect the large weight of evidence obtained by solid sampling in the stack, and it is difficult to accept the idea that the top gas ratio is determined at the tuyere level. Any small amount of reduction in the stack is regarded as reversed by oxidation in the tuyere zone, the extent of which the author seems to overestimate. The furnace is thus divided at the tuyere level into a zone of heating and fusion, and the hearth where direct reduction occurs. This reduction is attributed to interaction between coke and oxidized iron slag at temperatures above a "temperature of inertia." On the basis of these concepts, such factors as tapping cycle, burden preparation, and the effects of blast temperature, coke charged, blowing through secondary tuyeres, and oxygen enrichment are discussed. The reviewer cannot judge how useful furnace operators will find the rules of operation given, but it is felt that the evidence put forward by the author in support of his "principles" is equally capable of explanation by more conventional theories.—A. Grieve.

NEW PUBLICATIONS

Aldrich, B. M. "*Ferromagnetism and the Curie Point.*" (Oklahoma Engineering Experiment Station Bulletin No. 83). 8vo, pp. 42. Stillwater, Okla., 1952: Oklahoma A. and M. College. (Gratis)

American Society for Testing Materials. "*Metal Cleaning Bibliographical Abstracts* 1842–1951." Prepared by Jay C. Harris. Special Technical Publication No. 90-B. 8vo, pp. iii + 132. Philadelphia, Pa., 1953: The Society. (Price $4.25)

American Society for Testing Materials. "*Symposium on Fatigue with Emphasis on Statistical Approach.*" Presented at the Fifty-Fifth Annual Meeting (Fiftieth Anniversary Meeting), American Society for Testing Materials, New York, N.Y., June 24, 1952. Special Technical Publications No. 137. 8vo, pp. [iv +] 91. Illustrated. Philadelphia, Pa., 1953: The Society. (Price $2)

American Society for Testing Materials. "*Symposium on Statistical Aspects of Fatigue.*" (Special Technical Publication No. 121.) Presented at the Fifty-Fourth Annual Meeting, American Society for Testing Materials, Atlantic City, N.J., June 19, 1951. 8vo, pp. [v +] 64. Illustrated. Philadelphia, Pa., 1952: The Society. (Price 12*s.* 6*d.*)

American Society for Testing Materials. "*Symposium on Testing Metal Powders and Metal Powder Products.*"

Presented at the Cleveland Spring Meeting, American Society for Testing Materials, March 5, 1952, Special Technical Publication No. 140. 8vo, pp. [v +] 87. Illustrated. Philadelphia, Pa., 1953: The Society. (Price $2)

BARNETT, E. DE BARRY, and C. L. WILSON. "*Inorganic Chemistry.*" Pp. xiv + 512. London, 1953: Longmans Green and Co. (Price 35*s.*)

"*The Blacksmith's Craft.*" An introduction to smithing for apprentices and craftsmen. (Rural Industries Bureau publication No. 54.) 8vo, pp. xii + 108. Illustrated. London, 1952: Rural Industries Bureau. (Price 8*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 622: 1953. "*Cyanides for Electroplating.*" 8vo, pp. 12. Illustrated. London, 1953: The Institution. (Price 2*s.* 6*d.*)

DENCKEWITZ, ROLF. "*Verbandsverhältnisse und Gefügeanalyse von Erz und Nebengestein des Erzvorkommens Lindenberg am Südwestrand der Lahnmulde.*" (Hessisches Lägerstättenarchiv. H. 2.) 4to, pp. 87. Illustrated. Wiesbaden, 1952: Hessisches Landesamt für Bodenforschung. (Price DM 12.50)

DENIS-PAPIN, M., and J. BISTESI. "*Les fours d'electrométallurgie.*" La. 8vo, pp. 70. Illustrated. Paris, 1952: Edit. Desforges. (Price 600 fr.)

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. "Classified Geological Photographs." Selected from the Collections of the Geological Survey and Museum by Margaret O. Morris. La. 8vo, pp. iv + 125. London, 1952: H.M. Stationery Office. (Price 3*s.* 6*d.*)

"DIN-Taschenbuch 19. *Materialprüfnormen für metallische Werkstoffe.*" Zsgest. vom Fachnormenausschuss Materialprüfung Stuttgart. Hrsg. vom Deutschen Normenausschuss. 8vo, pp. 172. Berlin, Köln, Frankfurt-am-Main, 1953: Beuth-Vertrieb. (Price DM 12.40)

FAIRMAN, SEIBERT, and CHESTER S. CUTSHALL. "*Mechanics of Materials.*" La. 8vo, pp. 420. Illustrated. New York, 1953: John Wiley and Sons, Inc. (Price $5.75)

GÖBEL, E. F., and W. MARFELS. "*Die Oberflächenhärtung und ihre Berücksichtigung bei der Gestaltung.*" Pp. iv + 95. Illustrated. Berlin, Göttingen, Heidelberg, 1953: Springer-Verlag. (Price DM 9.–)

HERMAN, H. "*Brown Coal.*" With Special Reference to the State of Victoria, Commonwealth of Australia. 8vo, pp. 612. Illustrated. Melbourne: The State Electricity Commission of Victoria. (Price 84*s.*)

HOLZER, KARL A. "*Untersuchungen zum Verschleiss im Zylinder von Verbrennungsmotoren.*" Pp. 294. Illustrated. München, 1952: R. Oldenbourg. (Price DM 30.–)

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS. "*The Sixth General Assembly of the International Council of Scientific Unions, held at Amsterdam, October 1st to 3rd, 1952. Reports of Proceedings.*" Edited by F. J. M. Stratton. La. 8vo, pp. viii + 157. Cambridge, 1953: Cambridge University Press. (Price 7*s.* 6*d.*)

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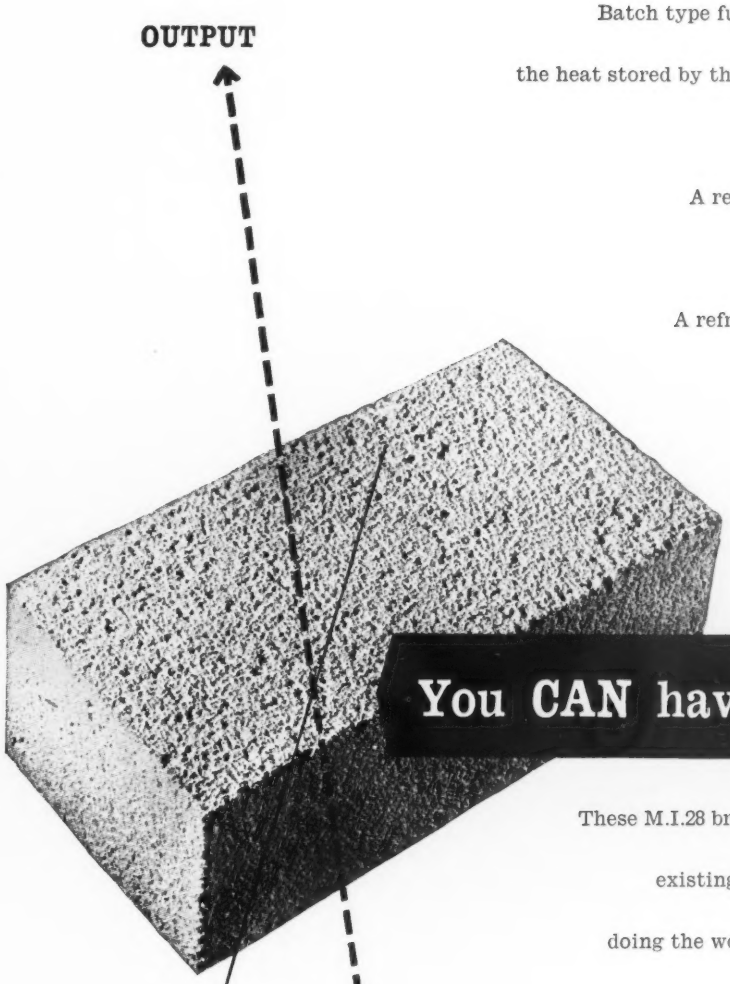

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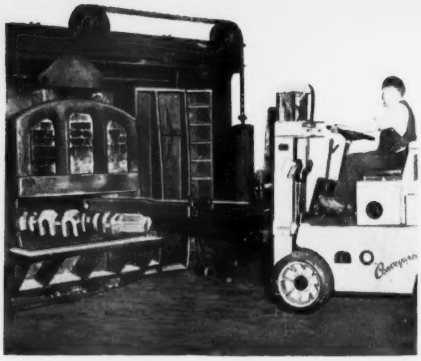

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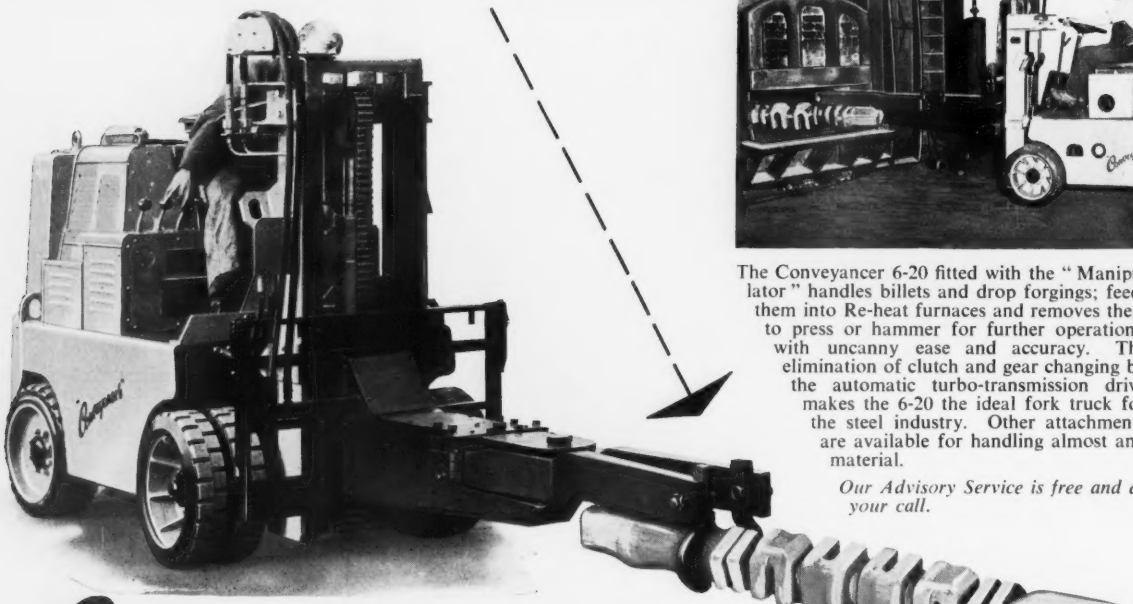

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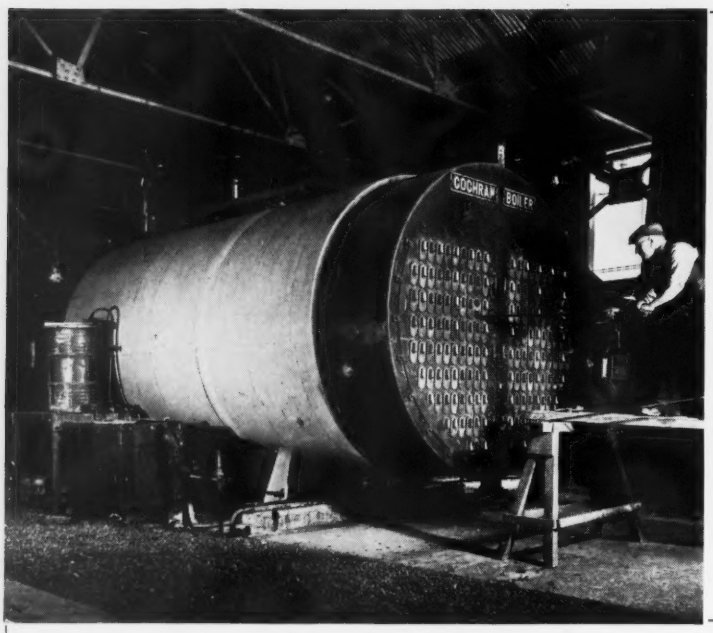

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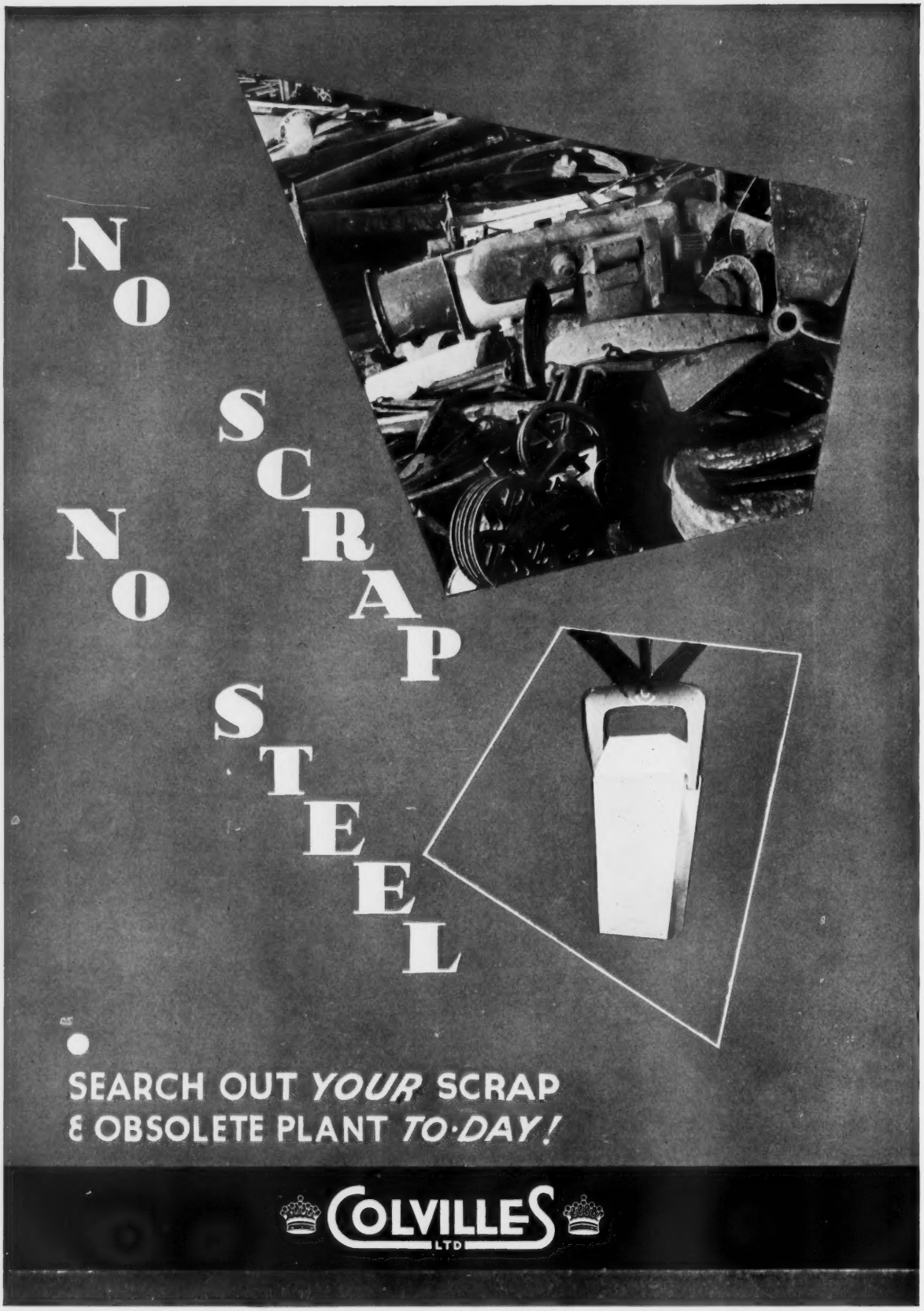

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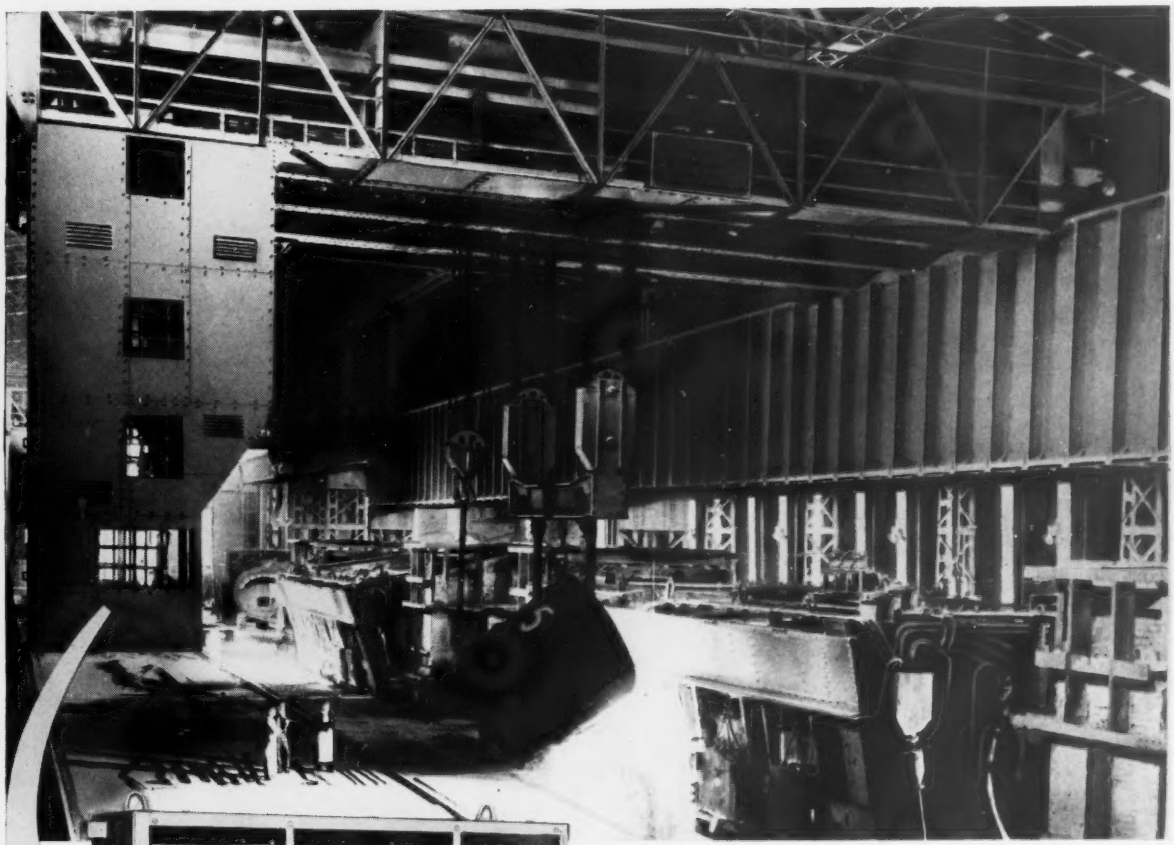

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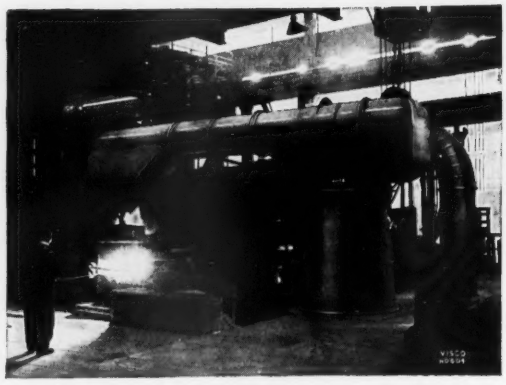

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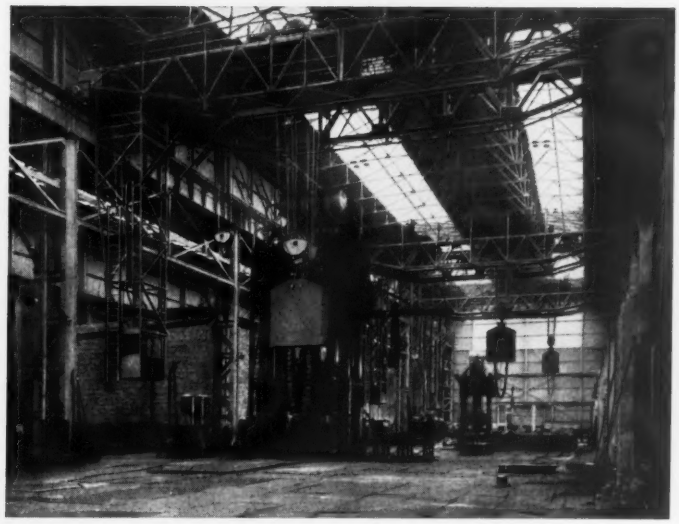

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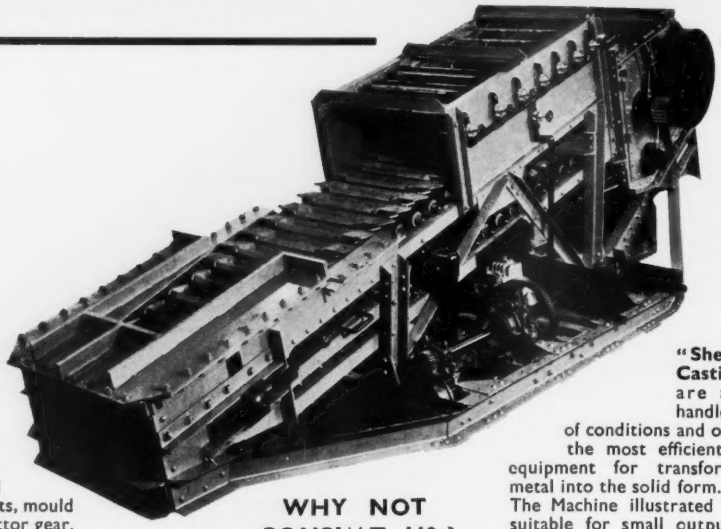

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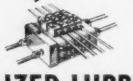

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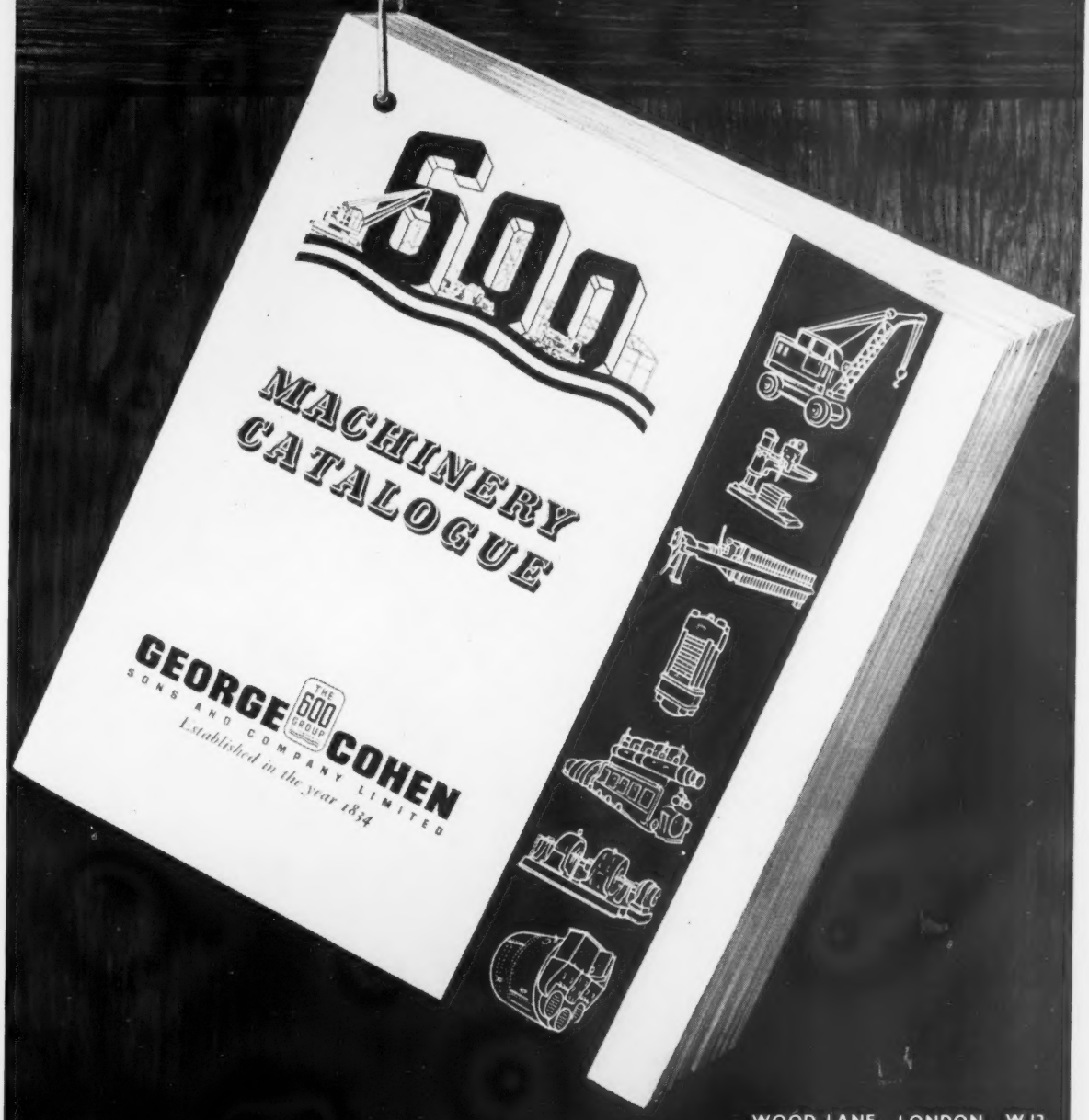

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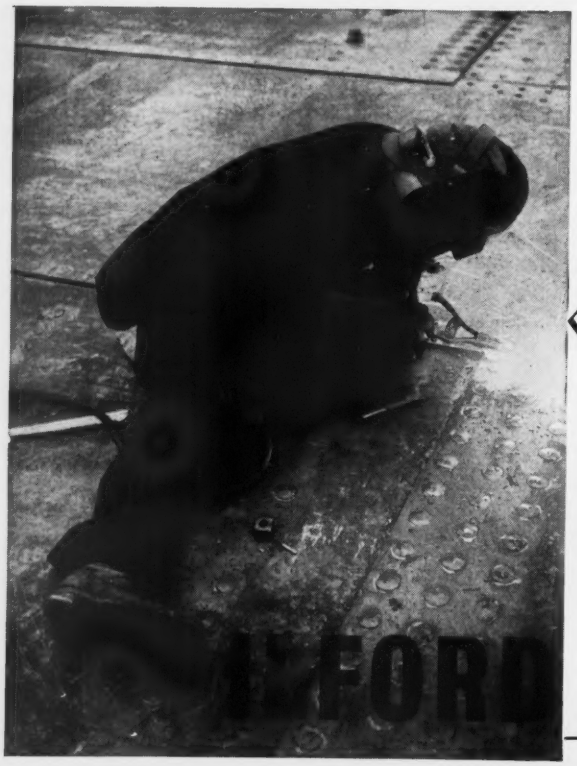

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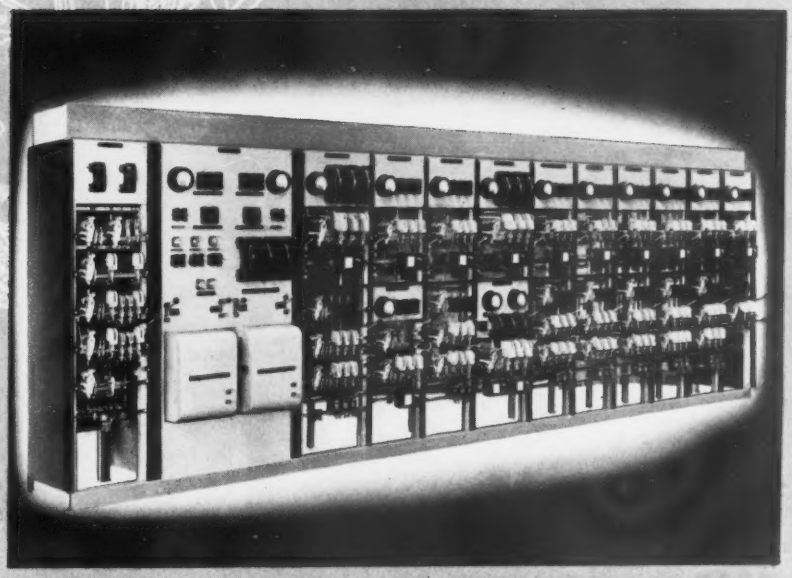

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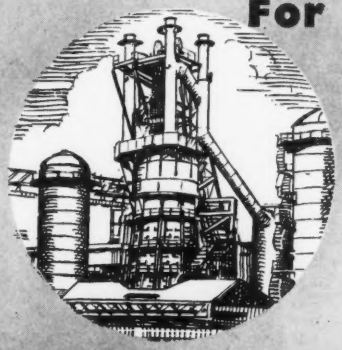

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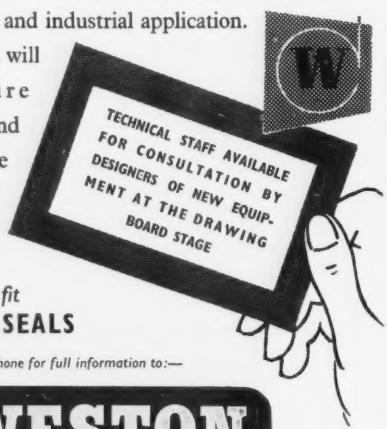

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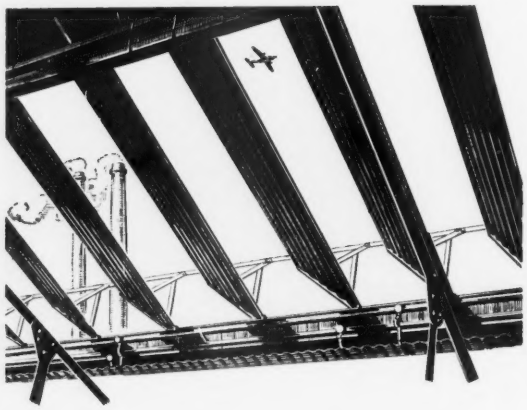

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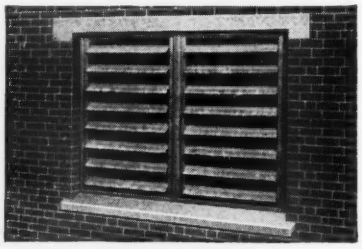

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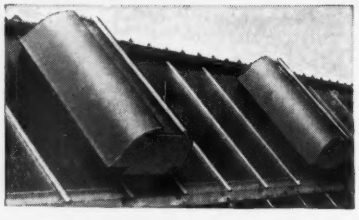

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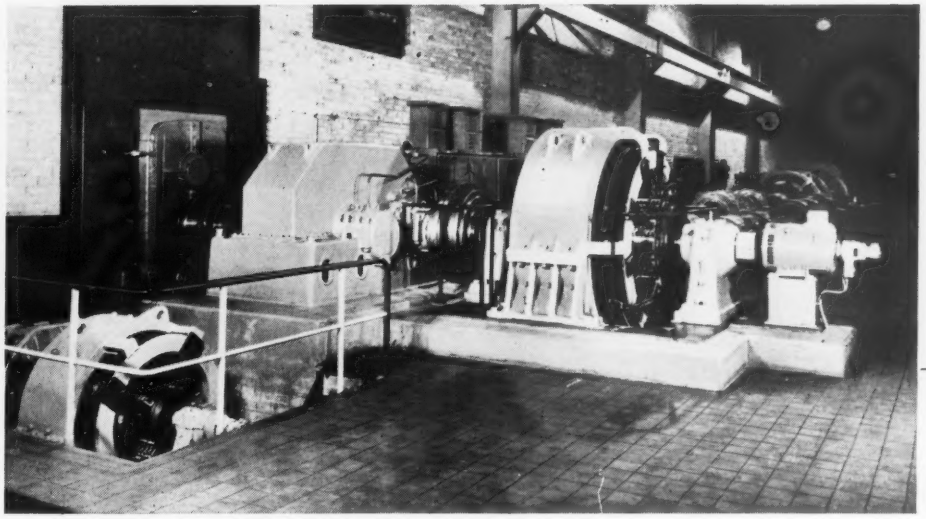

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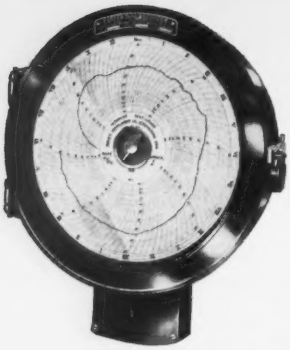

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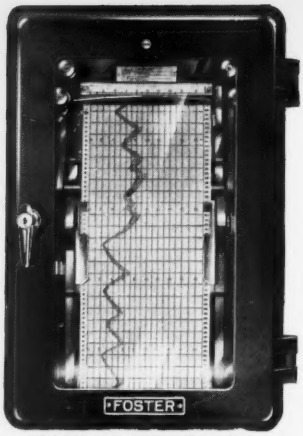

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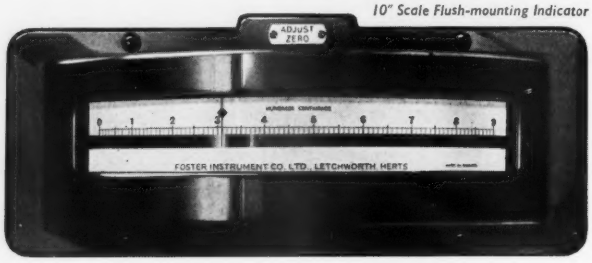

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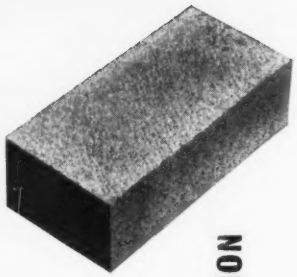

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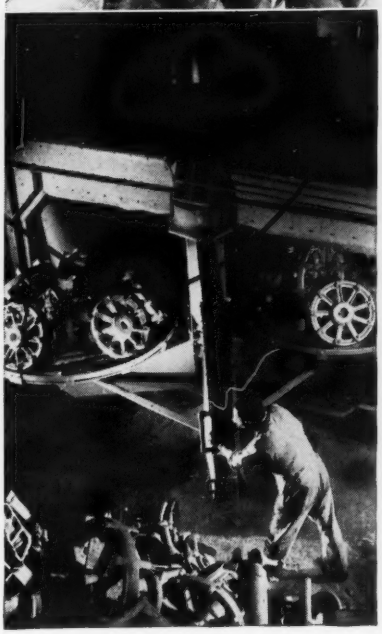

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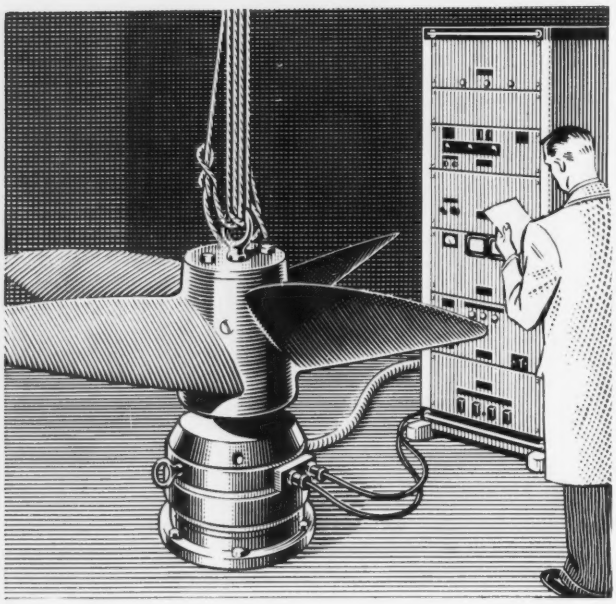

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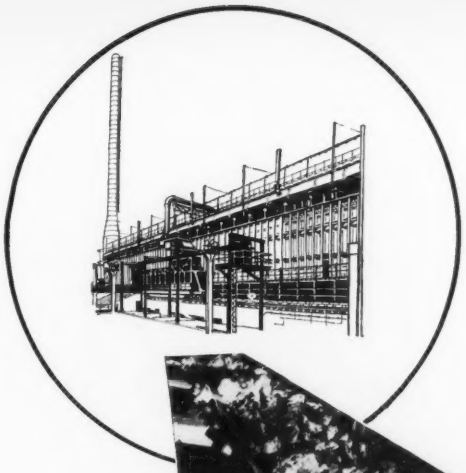

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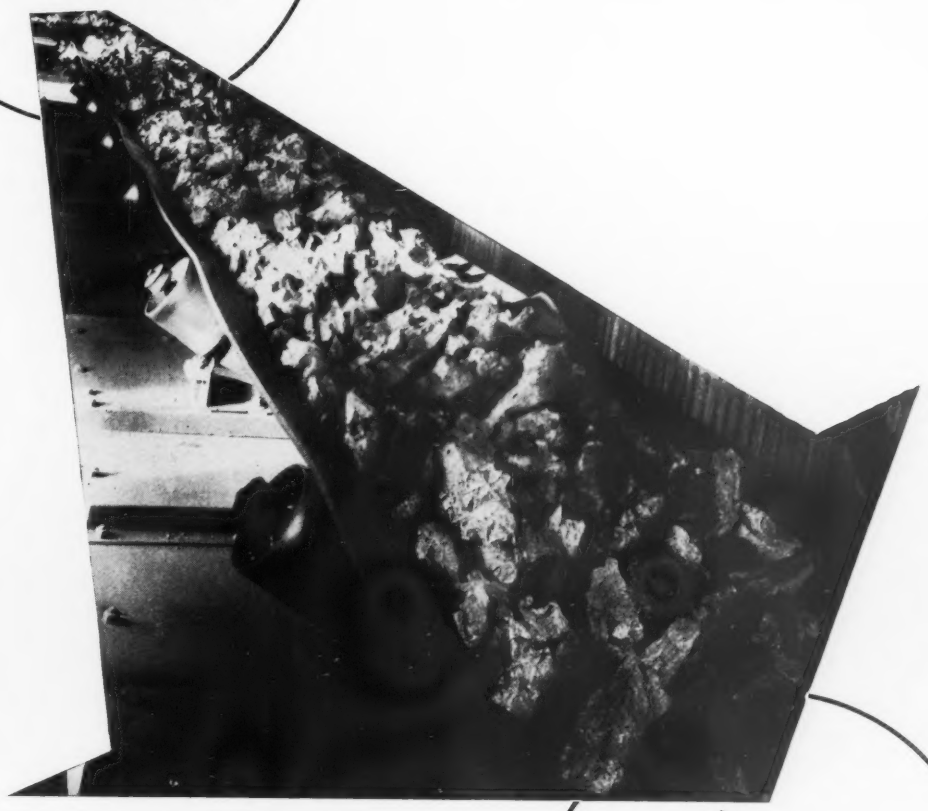

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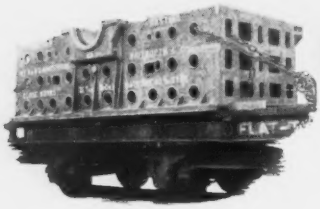

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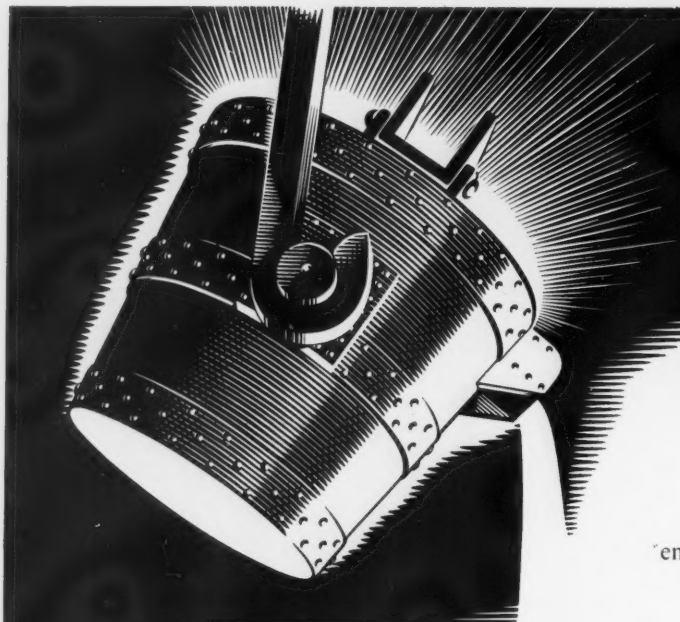

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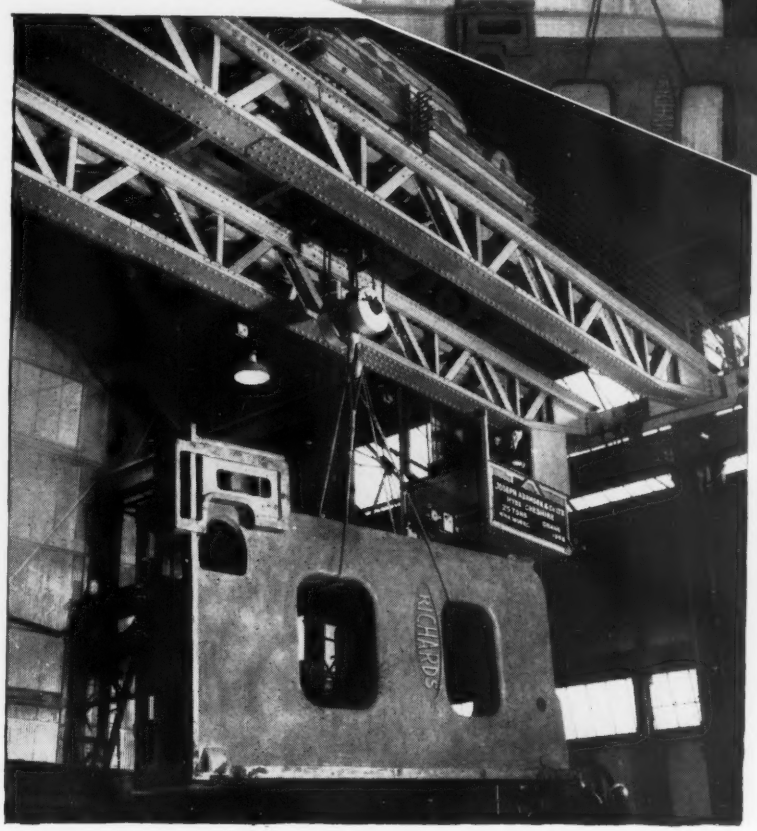

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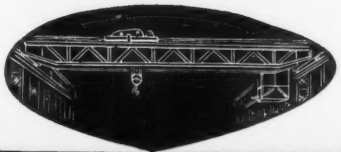

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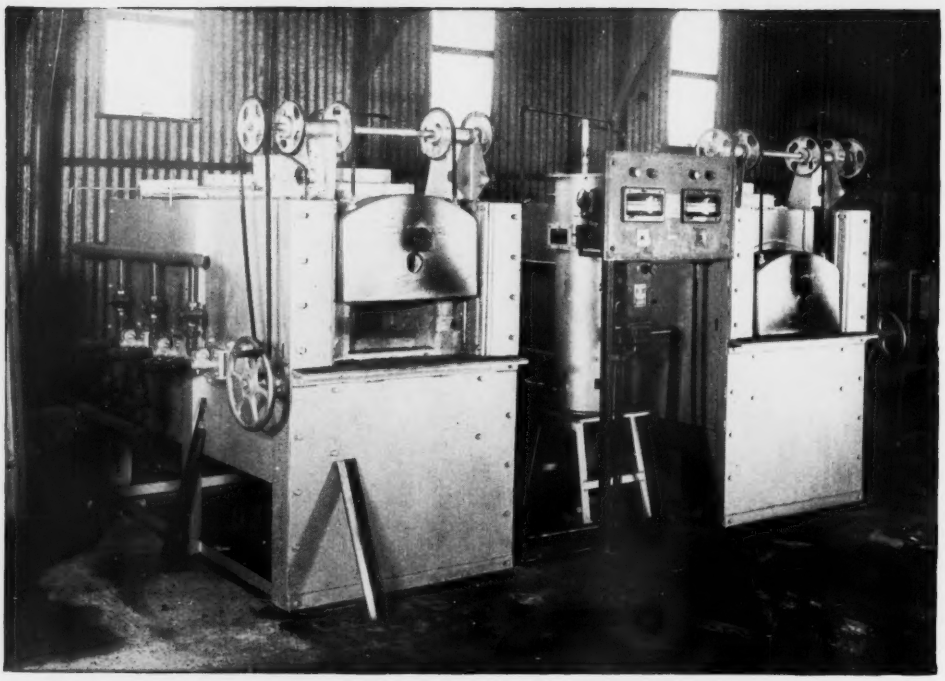

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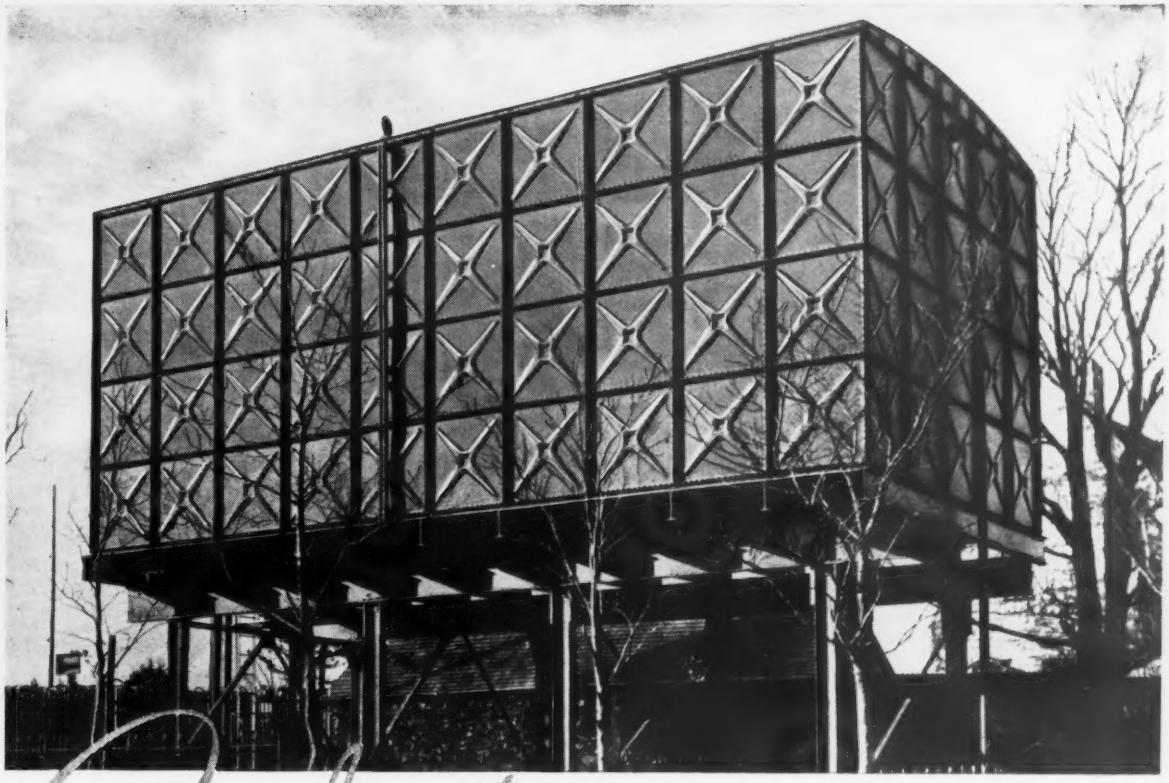

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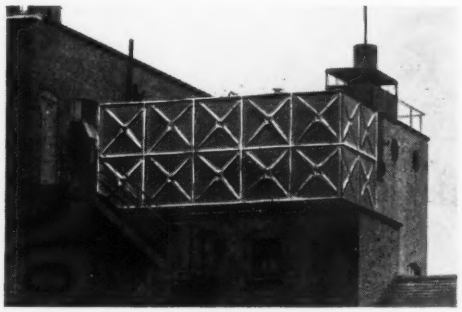

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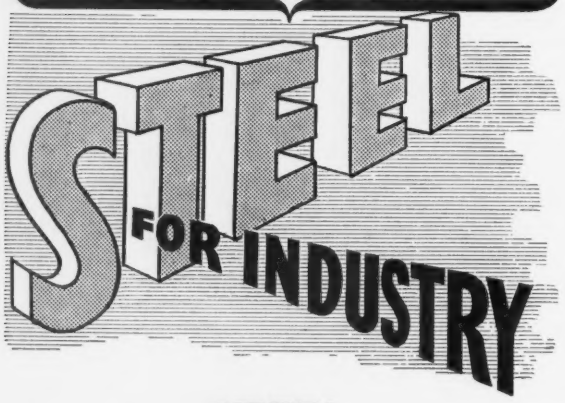

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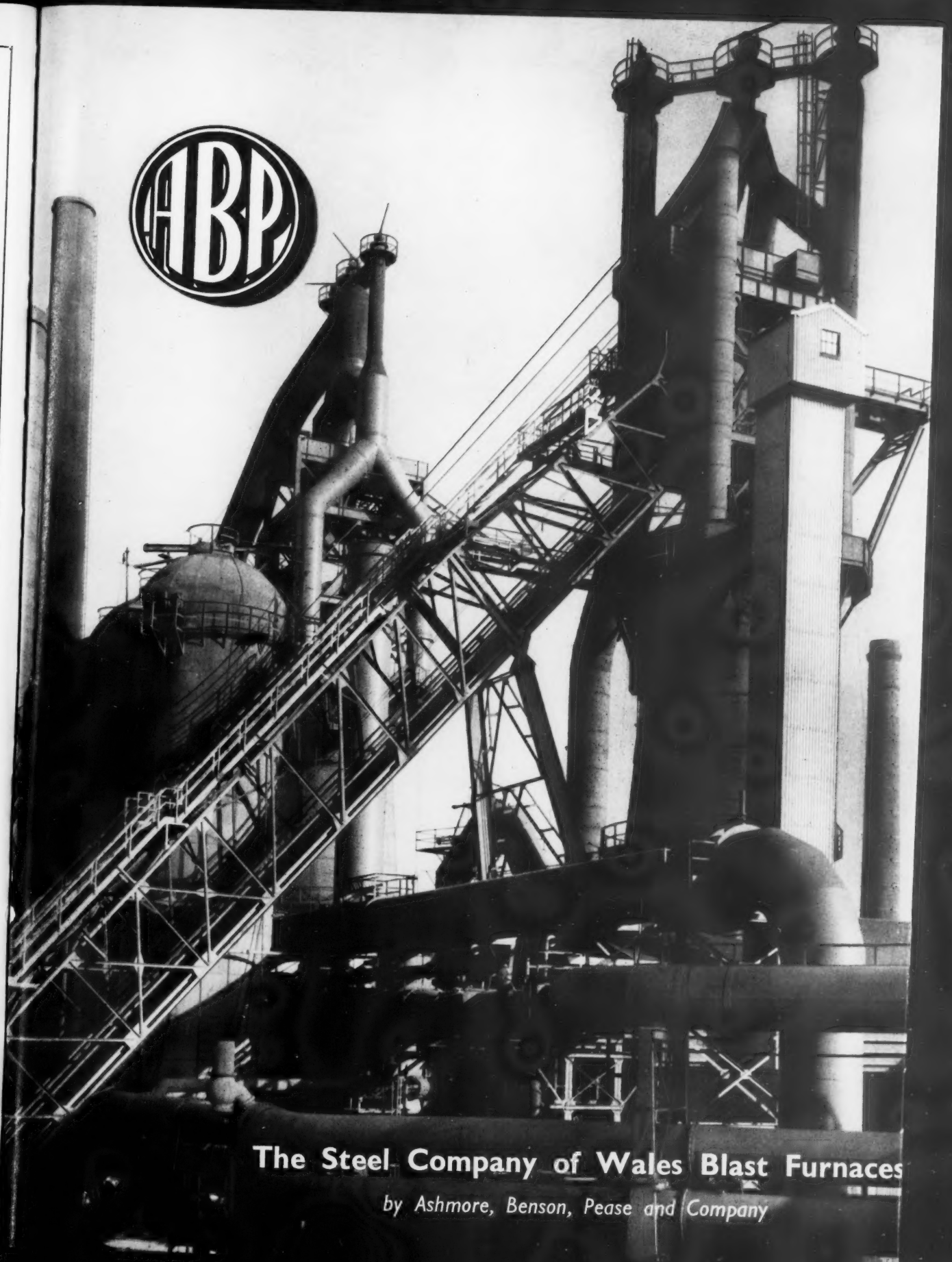
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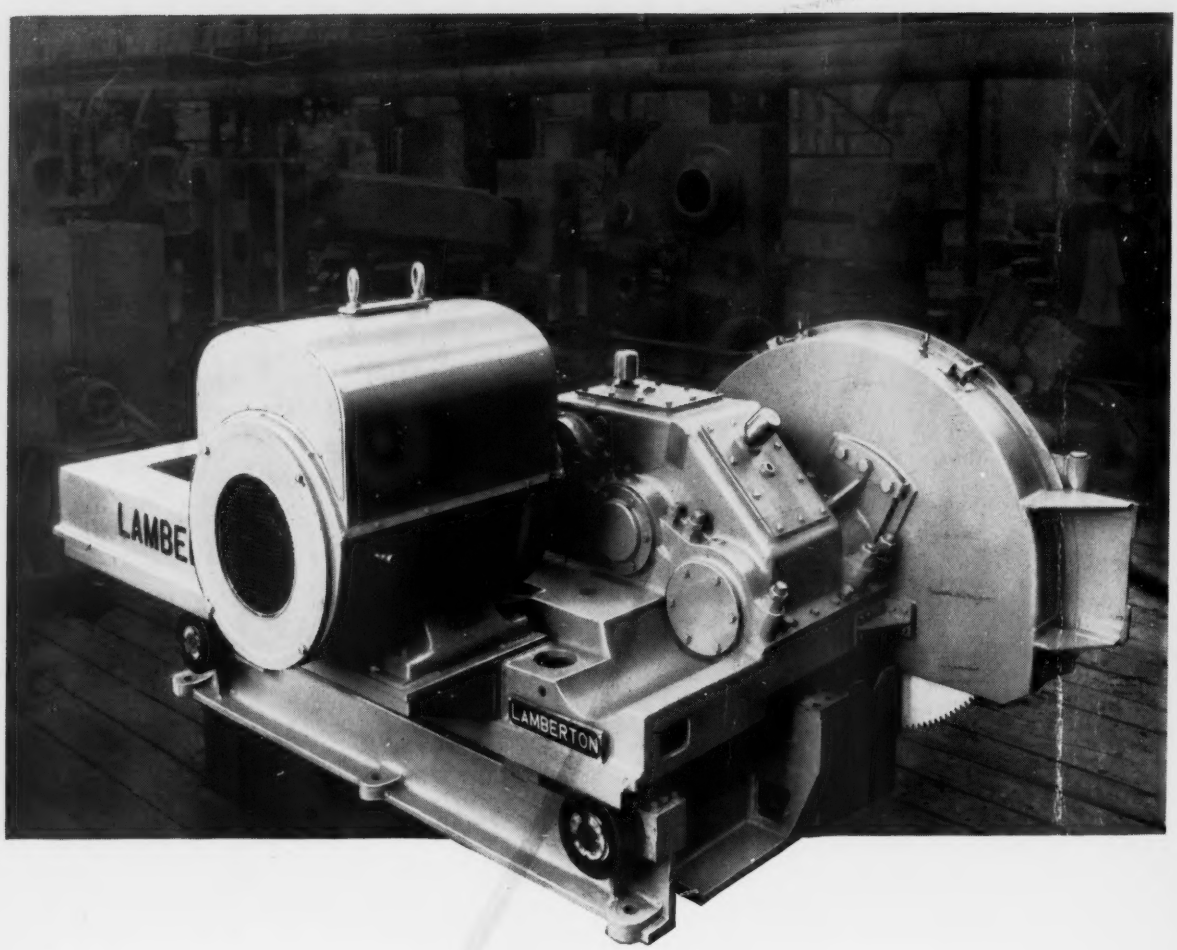

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